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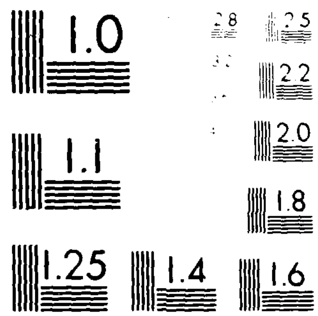

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A PRODUCTIVITY MEASUREMENT MODEL
APPLICATION AT AN AIRCRAFT MAINTENANCE
FACILITY

by

Owen R. Fletcher Jr.

December 1980

Thesis Advisor: John W. Creighton

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A Productivity Measurement Model
Application at an Aircraft Maintenance
Facility

by

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Submitted in partial fulfillment of the
requirements for the degree of

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Productivity is a concept which generates a great deal of discussion in business and economic circles. This interest has precipitated research into the area of productivity measurement. In this study, a model developed to measure productivity at the firm level is modified and applied to the operations at a large commercial aircraft maintenance facility. The results not only address productivity areas, but also pricing decisions and overall profitability.

Recommendations are made for improving the pricing procedures used at the facility and the labor output data collection process.

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I. INTRODUCTION

The subject of productivity improvement is receiving unprecedented attention these days, largely due to the fact that it is one of the most effective weapons against inflation. Traditionally, researchers and management have emphasized productivity improvement when, in reality, improvement is but one part of the cycle of productivity.

This cycle of productivity is an on-going process which, once set in motion, keeps on repeating itself. The first step is productivity measurement, followed by evaluation, planning, and finally improvement. Concentrating just on improvement, without due consideration to the other steps in the cycle, is akin to attempting space flight before learning how to walk.

A large commercial aircraft repair facility, concerned about productivity improvement and recognizing the productivity cycle relationships, commissioned a study on productivity measurement [Ref. 9]. That study, geared around one of the facility's operating departments, paved the way for additional work in the measurement area. In this project, the purpose was to design and apply a total productivity measurement model capable of accounting for not just one department, but the entire facility.

Aircraft maintenance is a unique and extremely diverse business. It is primarily a job shop process that requires substantial expenditures for skilled labor and plant facilities. For a commercial aircraft, maintenance is performed in accordance with manufacturer recommendations,

usage, and Federal Aviation Administration (FAA) regulations. Certain types of mechanics and technicians must be routinely licensed and certified in order to perform specific repair actions. On a routine overhaul visit, an airframe might have all the passenger seats removed and refurbished, a complete exterior painting, engines overhauled, and a new entertainment package (movie and music) installed. Being able to measure the "productivity" of just one of these tasks is a tall order; measuring the "productivity" of aircraft maintenance in general can be a monumental undertaking.

In the ensuing chapters, the design and application of a total productivity model is carefully detailed. The model used in the study is selected from current research and was used in the initial study of productivity measurement at the facility. Data required by the model must be sourced, and where needed, manipulated into a useful format. Any problems that may be associated with the data or the collection process must either be resolved, or stated "up-front" in order to alert the users of the results. Finally, the results obtained, largely because of the specific model which was selected, can be used to address not only productivity, but pricing decisions and overall facility profitability as well.

Far from being an exercise developed solely for the classroom, the work detailed here is directed at a "real world" problem. Consequently, easy solutions are not forthcoming, nor should they be. The results

which can be obtained are better used to sharpen the focus of management on the complex relationships involved in productivity.

II. BACKGROUND

A. DEFINITIONS

It is common knowledge for every consumer that inflation has seriously eroded the purchasing power of the dollar. The costs of providing goods and services have dramatically increased in recent years; however, the basic goods and services have not shown a corresponding increase in utility. Put a different way, that old nickel candy bar now costs twenty-five cents. For the manufacturer, wage demands of labor and higher costs for energy eat away profits. Passing along these increased production costs merely fuels the fire, causing yet another round of price and wage increases.

This is the classic description of the inflationary spiral, currently an economic reality, which threatens to destroy the American economic system. Another casualty of inflation is American productivity. Just as inflation has marched upward, productivity has steadily declined over the past two decades, in relation to other industrialized nations of the world. Table I displays current data from the Bureau of Labor Statistics on the rate of growth of productivity. Clearly the trend is ominous; if this decline is not checked, the pictures of idle auto assembly lines and steel mills which dominated the summer of 1980 will become the stark reality of the coming decade.

Stopping this decline in productivity will not be easy. First, the concept of productivity must be made clear; indeed the term itself has never really had a universally accepted definition. Second, in order to

TABLE I

WORLDWIDE PRODUCTIVITY COMPARISON

PRODUCTIVITY: ANNUAL PERCENTAGE INCREASE

DURING THE PERIOD	1960-66	1967-73	1974-80
CANADA	4.3	4.9	2.8
FRANCE	5.4	5.7	5.1
ITALY	7.3	6.6	3.3
JAPAN	8.5	10.0	4.2
WEST GERMANY	5.8	5.0	5.0
UNITED KINGDOM	4.1	3.8	0.6
UNITED STATES	4.2	2.9	2.1

Source: Bureau of Labor Statistics

improve productivity, somehow productivity must be measured. This implied capability to measure and adjudge productivity, a concept which itself is unclear, is definitely easier said than done. If there is a ground of common agreement among productivity experts and scholars, it is that America's productivity problems are poorly understood and inadequately measured.

Trying to define productivity is akin to the fable of the elephant and the three blind men. Everyone has his own interpretation of the facts.

> Ask workers what productivity means, and nine out of ten will say it means management squeezing more work out of the brothers, 'speed up' or 'elimination of jobs.' Ask economists, and they will define it as output per man-hour or 'total factor' productivity. Ask information scientists, and they claim that it means better, faster communications, better reporting mechanisms, and more information. Industrial engineers will declare that it means better utilization of capital and the employment of better, more efficient technology. Sociologists talk in terms of motivation and behavior. Management consultants will state that it involves better management practices, and social scientists will discuss change and improvements in work and organizational design structure. [Ref. 4]

Just as in the table, each of the above descriptions of productivity is correct for a very small area; however the totality of the definition has not been captured by any one of them.

To put into words a simple, yet powerful definition of productivity, one must first come to the realization that productivity is a resultant of many factors. According to Grayson, [Ref. 4], productivity is so complex that it must be treated in two different manners. From an abstract point of view, productivity can be said to consist of two basic parts; labor productivity and capital productivity. Each concept is separate and distinct, yet each is interrelated with the other.

Capital productivity is basically quantitative, dealing with areas that are measurable. Typical indicators of capital productivity are return on investment (ROI), profit margins, and the infamous "bottom line." In this area of productivity, the economist, the banker, the tax lawyer, the industrial engineer, and the comptroller are the most frequently encountered professionals. Nowhere in a discussion of capital productivity would there be a mention of environmental, social, or human factors unless they could be captured in hard quantitative measurements. Capital productivity measures output of human and machine labor by the same cold, quantitative criteria. Improvement is any manner, form, device, machine, system, or innovation which can lower unit costs and increase ROI.

Labor productivity, on the other hand, is essentially qualitative or humanistic. In this area can be found the concerns for the quality of work, job satisfaction, morale, and other activities which relate to the fullest utilization of purely human resources. Haunting the arena of labor productivity are the sociologists, social psychologists, personnel and industrial relations experts, job designers, and the organizational development experts. Strangely enough, the industrial engineer can also be found in this province; his efforts directed at the man-machine interface problem. Improvements in labor productivity are expressed in the same qualitative terms. The focus of those professionals working in the field is to promote a better synthesis of man and machine. [Ref. 4]

The dual definition of productivity seems to recognize the complexity of the term, and yet push to the forefront a common concept. That

is, at a very gut level, productivity implies the efficient and effective use of available resources. There are, however, problems with the dual definition, since in reality the capital productivity area is a composite of other areas, including energy, labor, capital investment, materials usage, and many more. Rather than accept a dual definition for productivity, that is a separation into capital and labor, it would seem more logical to merely concentrate on the concept of total productivity and not worry about where to draw the line of separation.

For the purposes of this thesis, a definition for productivity is best focused on the concepts of total productivity. It contains the elements of capital productivity and labor productivity, recognizing the complexity of each. It also reinforces the core conception of productivity mentioned earlier. Productivity can now be defined as an overall measurement of economic and human effectiveness on the basis of real output per unit of resources used.

Accepting this definition of productivity immediately demands that the term "productivity measurement" be defined. Conceptually, measuring productivity simply involves taking a ratio of the output and the inputs. The controlled fusion reactor is also "conceptually simple"; however, to date, no one has been able to build one. Measuring productivity, while intuitively simple, is really a Pandora's Box of problems. What constitutes an output and in what unit is it measured? By the same token, what should be defined as an input, and how are these to be quantified? How can a mixture of inputs and outputs be treated? In short, the simple ratio method is really not so simple.

Even though these serious objections exist, productivity measurement, within the context of this thesis, will be defined as the ratio of the output to the inputs. In a subsequent chapter, dealing with the mechanics of the measurement model, the proper justifications and implications of using this method will be discussed. For now, the definition of productivity measurement can be stated as follows: productivity measurement is the process of relating output and inputs in such a manner as to obtain an output unit per input unit.

B. HISTORICAL PERSPECTIVES

The study of productivity has grown out of the field of economics; consequently the first crude analyses and estimates of productivity began to appear about a century ago. These early estimates of productivity were in terms of output per unit of labor input. Most of the early economists had some sort of labor theory of production and value. Adam Smith, for example, wrote in 1776, "The annual produce of any nation can be increased in its value by no other means but by increasing either the number of its productive labourers, or the productive powers of those labourers who had before been employed." [Ref. 16] By the latter portion of the nineteenth century, most scholars had recognized that not only were labor and land basic factors of production, but that man-made capital goods had to be considered as well. This laid the framework for the classical economic production function and a new term, "productivity."

In the United States, the Bureau of Labor in the Interior Department published the first productivity estimates during the mid 1880's. Those

early estimates, based on the output-per-hour concept, were made due to the concern over the causes of industrial depression. Subsequent annual reports of the bureau contained estimates of productivity (hours and labor costs per unit of output) for a wide range of industries. Articles in the Monthly Labor Review, during the 1920's, further developed labor productivity estimation techniques. [Ref. 8]

During the 1920's and the years of the Great Depression, productivity became a "hot" topic. This renewed interest stimulated development of more sophisticated productivity estimates and analyses. The National Research Project of the Works Progress Administration mounted an intensive series of studies during that decade. Upon termination of the project in 1940, the productivity measurement work was transferred to the new Division of Productivity and Technological Developments in the Bureau of Labor Statistics of the U.S. Department of Labor, where it continued on a regular basis to this day. Initially, the productivity measures covered output per hour in selected industries. In 1958, a major step was taken by providing first annual, and later quarterly estimates of real product per hour for the entire private economy. These estimates were broken down into farm, non-farm, manufacturing, and non-manufacturing sectors. In recent years, selected productivity data on an international scale has been made available through the Bureau of Labor Statistics.

Worldwide, productivity centers have sprung up in most of the industrialized nations. These productivity centers emerged in the post

World War II era during the immense reconstruction efforts in Western Europe and Japan. Most of these centers are now multinational; for example, the original Japanese Productivity Center established in 1955 is now a component of the Asian Productivity Organization, comprised of fourteen other nations. It is interesting to note that the formation and operations, until 1961, of most of these foreign centers were backed by financial aid from the United States. [Ref. 12]

Strangely enough, no national productivity center was established in the United States until 1970. Early in the 1960's, statistics began to point toward a slowdown in U.S. productivity. By the late sixties, the productivity slowdown had contributed to a general downturn of the economy; accelerated inflation rates, decelerating growth of real wages, and the erosion of the value of the dollar. In June 1970, the National Commission on Productivity was created by executive order. In 1975, the National Center for Productivity and Quality of Working Life replaced the Commission. [Ref. 8] It was an attempt by President Carter to stimulate national efforts to implement a policy of

> "...productivity growth consistent with the needs of the economy, the natural environment, and the needs, rights and best interests of management, the workforce, and consumers." [Ref. 10]

The center's charter expired in 1978 and was not renewed.

This being an election year, and the status of the economy a highly charged campaign issue, President Carter has proposed a prescription for the nation's productivity and economic ills. Along with certain tax cuts--aimed at stimulating business capital formation and investment--and a job retraining program, the President has created the

Economic Revitalization Board This body, co-chaired by Irving Shapiro (chairman of DuPont) and Lane Kirkland (president of the AFL-CIO), will advise the White House on issues affecting U.S. Productivity. It will be specially charged with planning an "industrial development authority" which may, someday, take on the economic-development responsibilities of other governmental departments, most notably Commerce and Agriculture. [Ref. 15]

C. PRODUCTIVITY MEASUREMENT IN THE AIRLINE INDUSTRY

Historically, the commercial airline industry has measured maintenance productivity by relating flying hours or passengers flown to the number of employees involved in the maintenance function. [Ref. 13] At one large commercial aircraft rework facility, this approach has been discarded because of its potential to generate misleading and inaccurate data. Concerning the factors involved in aircraft maintenance, a potential lead or lag in the aircraft maintenance work performed, relative to the period when the aircraft was actually flown, could easily skew productivity data. Clearly a new airframe requires less maintenance than an older one and seasonal usage of the aircraft (greater passenger volumes in the summer months) make it more cost effective to perform more extensive maintenance during the winter months. Management began to develop their own measure of aircraft maintenance productivity which would recognize these and other factors.

The first step was an "earned hour" maintenance concept which effectively tried to equate the thousands of different activities involved

in airline maintenance to one "product." This "earned hour" concept will be discussed in much greater detail in a subsequent chapter (Chapter 5). The "earned hour" concept however was not a total productivity measurement, since it did not factor in the tradeoffs and contributions of capital, energy, and materials. [Ref. 13]

Utilizing components of the "earned hour" concept and a measurement model developed by the American Productivity Center [Ref. 6], the next step was to attempt a total productivity measure of one maintenance department at the rework facility. Subsequently a report dealing with this project was published. [Ref. 9]

The latest iteration, the subject of this report, is to expand and improve the previous work so that a productivity measurement model for the entire rework facility can be formalized. This involves not only one department, as was the case in previous work, but the entire spectrum of activities performed in the actual maintenance process and all support activities necessary for the facility to operate smoothly and effectively.

A word here about the facility itself. It is one of the world's largest and most modern aircraft maintenance centers anywhere. It employs upwards of eight thousand maintenance, inspection, engineering, and administrative personnel. It supports not only the fleet of the parent airline, but also performs maintenance for other airlines on a contract basis.

In order to perform the myriad of tasks associated with planning, implementing and monitoring a maintenance program, the facility is

organized into three functional areas: Airframes, Engines, and Aircraft Components. These departments actually perform the "wrench turning" duties associated with aircraft maintenance. In support of these operational departments, there are several staff departments such as Computer Services, Engineering, Supply, Personnel, Accounting, Contract Sales, and Food Services which perform the "housekeeping" and planning tasks associated with such a large scale operation. The maintenance operation is administratively separate from other airline functions, such as ticket sales and flight scheduling. The chief administrator at the facility reports directly to the corporate headquarters.

D. PREVIOUS RESEARCH INTO THE PRODUCTIVITY MEASUREMENT AREA

Prior research in the area of productivity measurement models suffers from a lack of quality. Until recently, the impetus for such research did not exist. However, one of the more classic pieces on productivity measurement models was performed by Hershauer and Rush at Lincoln Electric. [Ref. 7] This model, entitled the "Servosystem Model of Worker Productivity" went a step beyond any other research work in the area. It effectively freed managers and researchers of the "partial measure" trap by concentrating on the major factors concerning productivity. It was perhaps the first total productivity measurement model.

Since the Lincoln Electric Model was presented, first in 1975 and finally published in 1978, a number of other models have been developed. ALCOA Aluminum has developed a model which facilitates industry wide comparisons [Ref. 3] and the National American Wholesale Grocers Association

developed a model for warehousing. [Ref. 13] Doubtless there are many more models for measuring productivity and many may even be in use. The usefulness of each model, however, is typically limited to the single industry or function for which it was developed. Each, however, tries to adjudge the effectiveness and efficiency of a process or a service. One should consider that even a crude measure of productivity is much better than none at all. Bergen states that the most important issue is to develop even crude productivity relationships, since with time these can be refined. As the model is used, more and better understanding is gained of the measurement process and of productivity itself. [Ref. 2]

E. SUMMARY

The definitions of productivity and productivity measurement, while perhaps being conceptually simple, prove exceedingly difficult to definitize. Having been spawned in the field of economics, which may account for the hazy definitions, productivity has been poorly understood and inadequately studied since its beginnings. Measures of productivity in the airline maintenance industry, the subject of this project, were found to be misleading and inaccurate. Very recently, research has begun to focus on total productivity measurement and a new model for measuring productivity has emerged.

III. THE MODEL

A. THE AMERICAN PRODUCTIVITY CENTER MODEL, GENERAL COMMENTS

The recently founded American Productivity Center (APC), a privately funded non-profit organization, has undertaken the task of developing a comprehensive total productivity measurement model. In order to accomplish this, the APC study group began researching current state-of-the-art productivity measurement models in industry use. It was found that there were a variety of approaches, depending upon the industry. However, the results indicated two very important shortcomings of the present models; (1) most productivity measurement models, including those of the Bureau of Labor Statistics, are a "partial measure" only, and (2) seldom have the results of these measurement models been incorporated into the financial accounting systems of the firms. The "partial measure" objection refers to the fact that usually labor is the only reference to which output is indexed. In other words, most measurement models treat the input function as being singularly composed of labor. Output is therefore indexed against labor only.

The approach taken by the APC research team was to develop a total productivity model, one which would include all factors of input, not just labor. By considering all inputs, such as capital, energy, and materials as well as labor, it is possible to compare the tradeoffs between each input and productivity. For example, the effect of replacing labor with capital intensive equipment can be monitored by this measurement model.

Another desirable feature which the APC team sought to include in their model was to have the results from the productivity measurement model tie in with a firm's financial accounting system. Managers would then be more familiar with the productivity data, and use it along with the conventional financial data, when making decisions.

The APC productivity measurement model, as proposed, is a simple yet powerful tool in the hands of productivity conscious managers. The basic model can be simply adapted to any industry, or set of operating conditions. As with most other productivity measurement models, the APC model utilizes indices which relate performance between two operating periods. In the case of the APC model, the indices relate output to input ratios in the current period to output to input ratios in an initial or base period.

The three indices used in the APC model are: (1) the Productivity Index, (2) the Cost Effectiveness Index, and (3) the Pricing Recovery Index. In addition, the results of the model are used in the tradition-al accounting technique of variance analysis.

B. THE PRODUCTIVITY INDEX

In the APC model, the productivity index relates quantity ratios in a current period to quantity ratios in a base period. These quantity ratios are price-weighted ratios rather than physical quantity ratios. A base period, or Laspeyres, weighting is used to compute the measure-ment. The intent is to demonstrate the change in quantitites while

holding price constant over the periods of consideration. The productivity index relationship is given in Equation 1A.

EQUATION 1A: LASPEYRES PRODUCTIVITY INDEX

$$\text{PRODUCTIVITY INDEX} = P = \frac{\dfrac{\text{Current Output Quantities}}{\text{Base Output Quantities}}}{\dfrac{\text{Current Input Quantities}}{\text{Base Input Quantities}}}$$

Mathematically, this relationship translates into Equation 1B.

EQUATION 1B: LASPEYRES PRODUCTIVITY INDEX

$$P = \frac{\dfrac{Q_2^U \; P_1^U}{Q_1^U \; P_1^U}}{\dfrac{Q_2^I \; P_1^I}{Q_1^I \; P_1^I}} = \frac{QI^U}{QI^I}$$

where Q_1^U = Output quantity in base period

Q_2^U = Output quantity in current period

Q_1^I = Input quantity in base period

Q_2^I = Input quantity in current period

P_1^U = Price of output in base period

P_1^I = Price of input in base period

QI^U = Laspeyres output quantity index

QI^I = Laspeyres input quantity index

P = Productivity Index (Period 2 to Period 1)

[Ref. 6]

A word here about interpretation: The base year productivity index, as well as the cost effectiveness index and the pricing recovery index, is set at unity. An increase in productivity, over the base year, is indicated by the index registering a value greater than one. A decrease in productivity would register as a value of less than one. If productivity were to remain constant, the value would remain at unity. This structure allows the decision maker a simple and convenient method for "reading" the results of the model.

C. THE COST EFFECTIVENESS INDEX

The cost effectiveness index relates value ratios of outputs to value ratios of inputs for the two periods under consideration. This index reflects how costs for the current period compare with a cost relationship established for the base period. The base period costs can be seen as "ideal costs," a goal to be approached or bettered in subsequent periods. Obviously this implies that the base period should be chosen carefully or the resulting data may be skewed. The importance of the cost effectiveness index is that it shows the degree of change in costs relative to sales revenues. Should sales revenues increase at a greater rate than costs, cost effectiveness will then increase. Conversely, if sales revenues decrease, remain constant, or increase at a slower rate than cost increases, cost effectiveness will drop..

Conceptually, the equation for the cost effectiveness index is given by Equation 2A.

EQUATION 2A: COST EFFECTIVENESS INDEX

$$\text{COST EFFECTIVENESS INDEX} = E \; \frac{\dfrac{\text{Current Output Value}}{\text{Base Output Value}}}{\dfrac{\text{Current Input Value}}{\text{Base Input Value}}}$$

Mathematically, the cost effectiveness index is given by Equation 2B

EQUATION 2B: COST EFFECTIVENESS INDEX

$$E = \frac{\dfrac{Q_2^U \; P_2^U}{Q_1^U \; P_1^U}}{\dfrac{Q_2^I \; P_2^I}{Q_1^I \; P_1^I}} = \frac{VI^U}{VI^I}$$

where: Q_1^U = Quantity output in base period

Q_2^U = Quantity output in current period

P_1^U = Output price in base period

P_2^U = Output price in current period

Q_1^I = Quantity input in base period

Q_2^I = Quantity input in current period

P_1^I - Input price in base period

P_2^I = Input price in current period

VI^U = Output value index

VI^I = Input value index

E = Cost Effectiveness Index

[Ref. 6]

D. THE PRICING RECOVERY INDEX

The pricing recovery index reflects the changes in pricing recovery over the periods in question. Basically it relates the price ratios of outputs to price ratios of inputs. This information shows to what extent the firm has been able to absorb the increases in prices of inputs and, therefore, been able to combat inflation. To derive this information, a current period, or Paasche, weighting is used.

Conceptually, the pricing recovery relationship is given by Equation 3A.

EQUATION 3A: PRICING RECOVERY INDEX

$$\text{PRICING RECOVERY INDEX} = R = \frac{\dfrac{\text{Current Output Price}}{\text{Base Output Price}}}{\dfrac{\text{Current Input Price}}{\text{Base Input Price}}}$$

Mathematically, the pricing recovery index formula is given by Equation 3B.

EQUATION 3B: PRICING RECOVERY INDEX

$$R = \frac{\dfrac{Q_2^U \; P_2^U}{Q_2^U \; P_1^U}}{\dfrac{Q_2^I \; P_2^I}{Q_2^I \; P_1^I}} = \frac{PI^U}{PI^I}$$

where: Q_1^U = Quantity output in base period

Q_2^U = Quantity output in current period

P_1^U = Output price in base period

P_2^U = Output price in current period

Q_1^I = Quantity input in base period

Q_2^I = Quantity input in current period

P_1^I = Input price in base period

P_2^I = Input price in current period

PI^U = Paasche output price index

PI^I = Paasche input price index

R = Pricing Recovery Index

[Ref. 6]

E. VARIANCE ANALYSIS

In addition to calculating the indices described above, the APC model provides for the use of a common accounting technique, variance analysis. Variances are defined as the difference between actual price and/or quantities and so-called "standard" prices and quantities. Variance analysis is actually a form of input/output analysis which allows one to focus on the output dollar contribution of individual input resources. The performance of each element of the resource used, in relationship to profitability, is then expressed in dollars. Variance analysis is used not only to express profit contribution relationships, but also to indicate priorities for improvement actions.

Variance analysis (and performance reporting systems) provides a vehicle for implementation of the management by exception concept. Since management's time is limited, it must be effectively utilized, concentrating on the areas where improvements are most sorely needed.

Variance analysis serves as the lens through which management can focus its limited time resources on the problems which are most important. Put another way, variance analysis allows the manager to identify those areas which need his attention and at the same time, he also identifies those areas where operations are running smoothly. [Ref. 1]

The APC model allows for the calculation of three variations. The first, a cost effectiveness variance, can be defined as the difference between the change in value of the products and the change in value of the resources used. This gives the decision maker an initial indication of the contribution of each resource used to the attainment of the overall goals of the firm. The formula for the cost effectiveness variance is given by Equation 4.

EQUATION 4: COST EFFECTIVENESS VARIANCE

$$\text{COST EFFECTIVENESS VARIANCE} = C_1 = V_1^{I}\,(VI^{U} - VI^{I})$$

where: VI^U = Output value index

VI^I = Input value index

V_1^I = Value of a specific input during the base period (Price of input times quantity)

C_1 = Cost Effectiveness Variance [Ref. 6]

The second variance which can be calculated is called the productivity variance. This reflects the difference between the change in the quantity of the product and the change in the quantity of the resources used. The productivity variance shows to what extent any resource element has contributed to the efficiency of the firm's attempt

to attain its goals. The equation for the productivity variance is given by Equation 5.

EQUATION 5: PRODUCTIVITY VARIANCE

$$\text{PRODUCTIVITY VARIANCE} = C_2 = V_1^{\,I}\,(QI^U - QI^I)$$

where: QI^U = Laspeyres output quantity index

QI^I = Laspeyres input quantity index

$V_1^{\,I}$ = Value of a specific input during the base period (Price of input times quantity)

C_2 = Productivity Variance

[Ref. 6]

The last variance is the pricing recovery variance which is the difference between the change in the price of a product and the change in the prices of the resources used to contruct that product. This data demonstrates to what extent the firm has passed on the increasing prices of resources. In other words, this gives an indication of how well the firm is combating inflation. The extent to which prices have been absorbed is directly related to an increase in productivity. Equation 6 gives the formula for the pricing recovery variance.

EQUATION 6: PRICING RECOVERY VARIANCE

$$\text{PRICING RECOVERY VARIANCE} = C_3 = V_1^{\,I}\,(VI^U - VI^I) - V_1^{\,I}\,(QI^U - QI^I) = C_1 - C_2$$

[Ref. 6]

F. COMMENTS AND SUMMARY

In order to measure the productivity performance the American Productivity Center has proposed a simple, yet powerful model. This

chapter has served to introduce the concepts of that model and the associated mathematics. Basically the model provides for the calculation of three indices: a productivity index, a cost effectiveness index, and a pricing recovery index. Given these, the model will also generate three associated variances: the productivity variance, the cost effectiveness variance, and the pricing recovery variance.

A word here about the relationships between the productivity, cost effectiveness, and pricing recovery indices. It should be noted that the cost effectiveness index is the product of the productivity index and the pricing recovery index. This relationship is further described by Equation 7.

EQUATION 7: PROFITABILITY EQUATION

$$E = P \times R$$

[Ref.6]

As pointed out earlier in the chapter, cost effectiveness shows the degree of change in costs relative to sales. If sales revenues increase faster than costs, cost effectiveness goes up. Given Equation 7, it can be seen that the increase in cost effectiveness is due to either productivity increasing or product prices increasing faster than input prices, or both. Since cost effectiveness is tied directly to profitability, productivity is also directly related to profitability. This relationship, profitability to productivity, is perhaps the key feature of the APC mode. [Ref. 6]

The APC model is not proposed as a replacement for normal budgetary and accounting systems. Rather, it is intended as an additional source of information for the manager/decision maker. Neither is the APC model designed to increase the "paper mill" at the management level. During the data gathering phase of the project, it was found that almost all of the information needed for the model was available from normal operational expense reports. Some data manipulation was necessary to obtain the exact format required, but by and large the basic information already existed and was being reported. The APC model merely arranged the data in a logical sequence, from which productivity decisions can be made more efficiently.

IV. BASIC DATA REQUIRED FOR THE PRODUCTIVITY MODEL

Aircraft maintenance is a complex and seemingly endless evolution. The necessary components, or inputs, for this process are equally complex and diverse. This chapter will discuss the inputs and procedures used to convert the inputs into a common measure.

A total productivity model must include all the inputs and all the outputs of a particular process. Conceptually, a process can have any number of inputs. Figure 1 provides a diagram of possible inputs to be considered in a productivity measurement model. Obviously in an aircraft maintenance evolution, some of these inputs are meaningless. However, the diagraming of inputs is a useful technique to insure total coverage. Figure 2 is an adaptation of the input categories under consideration in this project.

The next item of concern is the common unit of measure to be used. A wide variety of actions, commodities, and services must be measured in order to assess productivity. The model requires that both inputs and outputs be measured in the same units in order that the ratio of the two (output to input) has meaning. Knowing that the unit of measure for input must also apply to output almost requires that inputs be stated as dollar equivalents. In other words, the unit of measure for inputs and outputs is the dollar. Fortunately, measuring inputs in terms of dollars is not hard. Most business firms keep detailed financial records of expenditures on labor, fuel, and material usage. Large business

corporations also take great care in recording the value of any inventory held on site. Records are also available on depreciation expenditures for plant and equipment.

For this particular project, input data is readily available from the company's operating expense reports. Certain manipulation of the data was required to obtain the format desired; however, this was minimal overall. In the sections that follow, an examination of each major input area is presented; the rationale and development of each is also discussed.

A. LABOR

The term "labor" sometimes carries the connotation of unskilled work. In terms of the aircraft maintenance evolution, one thinks immediately of the mechanic with wrench in hand when the term "labor" is used. This is unfortunate since not only do the "blue collar" mechanics comprise the labor effort of the facility, but the "white collar" planners and engineers also make significant contributions.

It is desirable, indeed mandatory, that in order to measure total productivity, the total labor force must be considered. A simple count of employment is usually not the best labor input measure, however. Such a count does not reflect the changes in labor input brought on by changes in the work week, shift assignment, or vacation. Therefore, it is better to use man-hours as the labor-input component. This measure can also be easily converted into dollars, simply by applying the average labor rate paid.

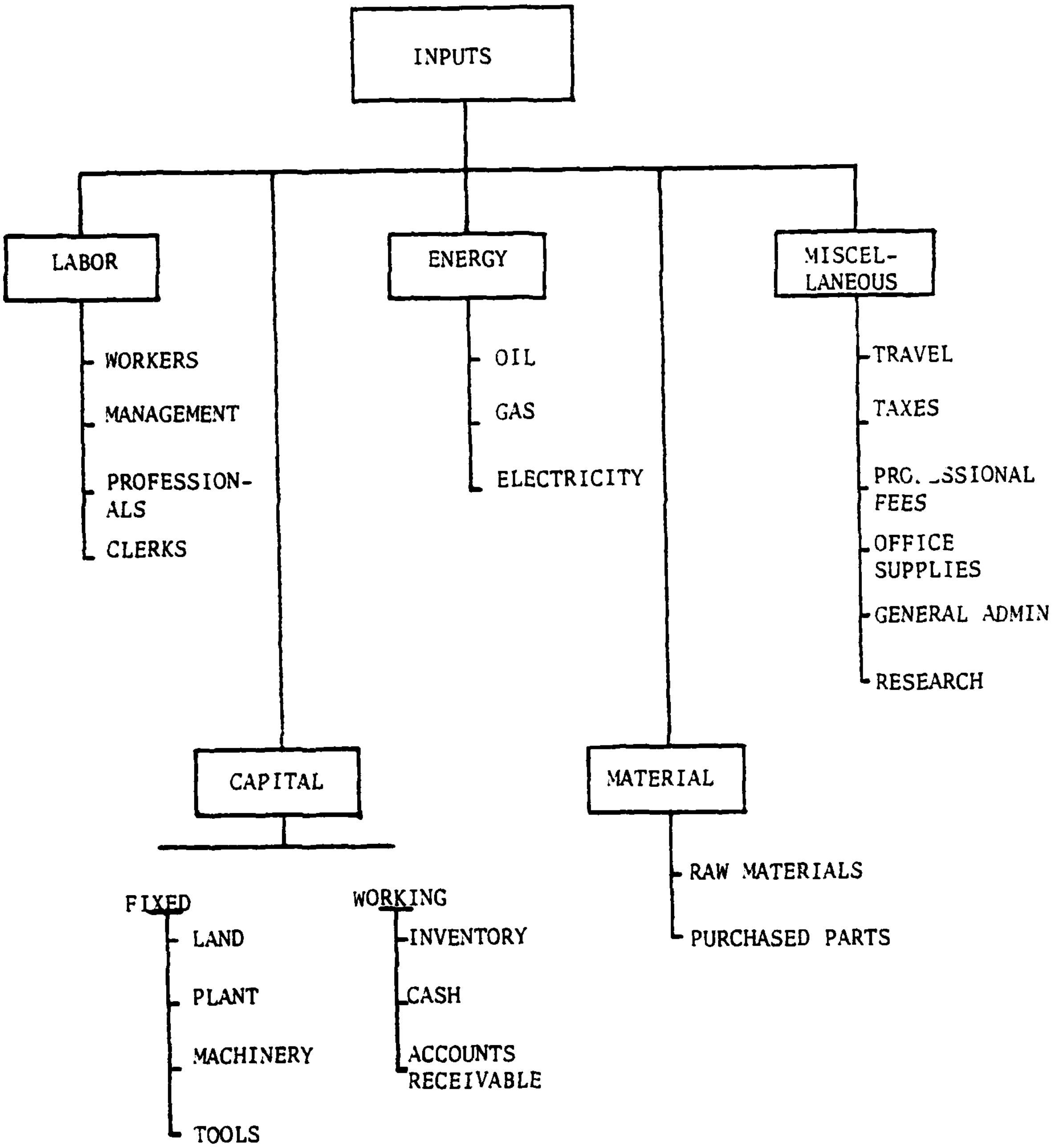

FIGURE 1. INPUT ELEMENTS CONSIDERED IN A TOTAL PRODUCTIVITY MODEL

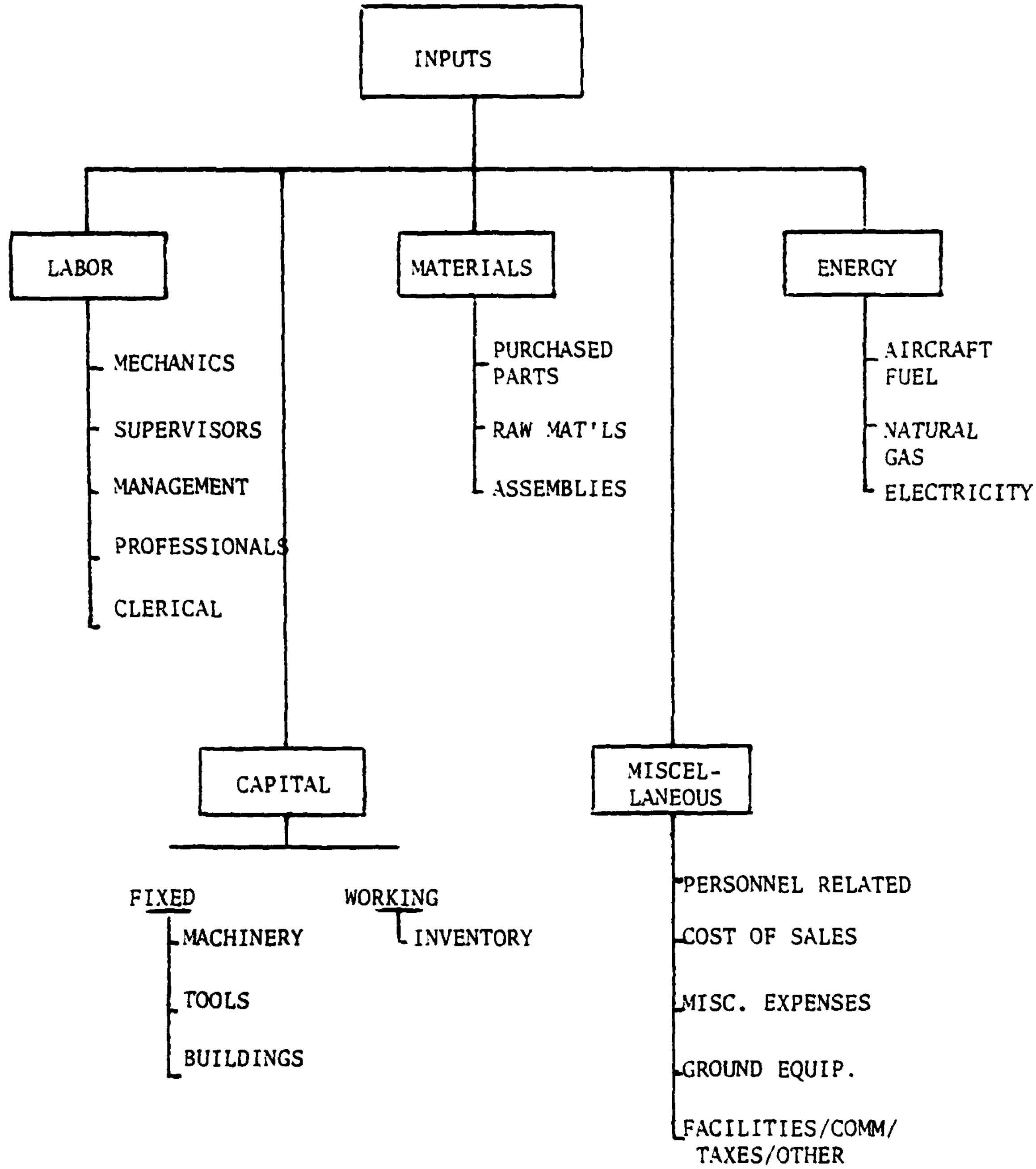

FIGURE 2. INPUT ELEMENTS CONSIDERED IN THE AMERICAN PRODUCTIVITY CENTER MODEL

There are two types of man-hour measures which can be used: "hours paid for" and "hours worked." Both are widely used, and the government publishes productivity statistics based on each. "Hours paid for" include all hours worked by employees plus hours not worked but paid for, such as paid vacations, sick leave, jury duty, etc. "Hours worked, by contrast, covers all hours at work including scheduled work, coffee breaks, rest periods, down time, etc. It includes all time within the scheduled work hours, whether the employee is actually working or not. It does not include any paid holiday, sick leave, or vacation periods. [Ref.5]

The use of "hours paid for" has three possible advantages: (1) It is a measure of the total man-hours that must be paid for in order to obtain a given amount of man-hours for productive work, (2) Data on hours paid for may be more readily available from accounting records, and (3) Most of the published information on hourly earnings is based on hours paid for. The disadvantage of the "hours paid for" concept is that it is affected in different ways by changes in work and vacation practices. For example, if the workweek is increased by overtime or decreased by workload reduction, the hours paid for will be increased or decreased in proportion. On the other hand, if vacation, holiday or other paid absences are increased, "hours paid for" are not affected.

The preferred labor input is "hours worked" although this measure has been the subject of much controversy and much misinterpretation. One of the major advantages of this concept is that it reflects all changes in vacation practices in the same way. If hours at work are reduced by a

shorter week, i.e. by vacations or holidays, the annual total of hours at work reflects these reductions.

Information on hours at work is generally available for a substantial portion of a firm's employees, including some who are paid on a salary basis rather than a wage basis. Records for professional, executive, and other such employees usually do not reflect overtime or temporary absence from the office, so estimates must be made. There are several techniques available, one being adjusting the scheduled hours using known employee practices or trends from records which are being kept. [Ref. 5]

In this project, the "hours worked" concept was used because: (1) It more accurately reflects the labor applied to aircraft, and (2) This data was available from the accounting records, requiring little manipulation. Having obtained an annual total hours worked, this was applied against the gross personnel expense (also from the accounting records) to obtain an average input labor rate. This rate reflects not only the mechanics, janitors, and other production workers, but also the administrative and staff personnel employed at the facility.

B. MATERIALS

Perhaps the easiest input to obtain is the annual expenditure on materials used in the manufacturing process. This data can almost always be obtained straight off the balance sheet of any company. The composition of material costs can be quite diverse, depending upon the type of business or industry under consideration.

In terms of the commercial aircraft rework facility, material expenditures are made for a number of commodity type items such as oil, grease, metal, and textile materials. At the same time, the maintenance of aircraft requires that specialized parts and assemblies also be purchased. One just doesn't manufacture an engine turbine blade down in the metal shop. Items like this are purchased from a supplier. Many times these purchased items are covered under a warranty and replacement costs of such items are reduced; therefore, warranty credits must also be counted.

The accounting records for material costs reflect a grand total of the materials used in the performance of aircraft rework projects at the facility. Other non-personnel expenses such as sales expenses, insurance, etc., are grouped under another input category.

C. CAPITAL

Capital input is perhaps one of the most important, yet one of the most difficult, inputs to measure. The composition of this input is very much open to controversy and speculation.

From a business perspective, capital refers to the holdings of a company, both tangible and intangible. For accounting purposes, capital is broken down into two areas, fixed and working. Fixed capital is comprised of land, plant (buildings and structures), machinery, tools, and other equipment. Working capital, on the other hand, includes money needed to support inventory, cash, accounts receivable, and notes receivable.

Traditionally there have been two methods for measuring the consumption of fixed capital. The first is the depreciation method and the second is the labor-input equivalent. This second method involves converting capital charges into labor-input equivalents and is of limited value for a productivity measurement model. A slight modification of the depreciation method will be used to obtain a capital input figure for the APC model. [Ref. 17]

Depreciation, according to the traditional accounting definition, is that portion of the initial cost of an asset which is expensed out during the period in order to account for wear or usage of the asset. [Ref. 1] The depreciation method makes use of the annual depreciation charges as an approximation of the fixed capital consumed. The difficulty with this method lies in actually representing the consumption of a fixed asset. What method of depreciation should be used? Clearly the most appealing would be the straight line method; however, very few companies depreciate their fixed assets in this manner due to the tax advantages provided by other depreciation methods.

With the concept of depreciation in mind, another way of determining the value of the annual capital outlay would be to consider the lease value of the assets. This leasing concept is essentially similar to depreciation and assumes that the firm must lease its fixed and working capital from a leasing subsidiary. Thus, the capital input corresponding to the period would be the payments made to the leasing subsidiary. This method is exceedingly well suited for the circumstances of the aircraft rework facility. Although corporate funds

were used to construct the facility, upon completion the facility was sold back to the municipal government and a leasing agreement was prepared. The corporation now pays a yearly fee, or rent, for the use of the land and buildings in which the facility is housed. This yearly fee is easily obtained from corporate accounting records and serves as a partial fixed capital input figure.

The balance of the fixed capital input figure is determined by using the depreciation charges for the period on the tooling and equipment used in the facility. The effect of using one depreciation scheme rather than another was seen to be minimal in terms of the average dollar figure per year; therefore, no attempt was made to manipulate these depreciation figures.

The working capital input for the rework facility is comprised of the inventory of spare parts kept on hand to support maintenance operations. After lengthy discussions with corporate officials on the inventory and its associated accounting systems, a formula for computing the inventory (working capital) contribution to capital input was decided. The inventory book value is obtained from accounting records. This value is essentially a moving average value of the parts in inventory reflecting past prices paid and current replacement costs. This inventory book value is then multiplied by the corporation's average cost of capital to obtain the working capital input figure. The intended explanation of this working capital input is to provide for the cost incurred by the corporation in keeping a specific dollar amount tied up in the inventory accounts.

The final capital input is merely the sum of the values of fixed and working capital.

D. ENERGY

Until recently, energy costs would not have merited special consideration. However, in today's economy, energy costs are often a large share of the operating expenses of a large company. In the total productivity model, the energy input is comprised of the costs incurred by using different energy sources.

For the aircraft rework facility, energy costs fall into three main areas: gas, electricity, and fuel. The gas component refers to the cost of natural gas used to generate the heat for the buildings. The electrical cost is incurred by the lights and other electrically powered equipment such as hangar doors, electroplating machines, and hoists. The fuel component refers to the use of both aircraft fuel and other fuel sources for the ground equipment at the facility. (The vast majority of these ground equipment vehicles are powered by propane.) Aircraft fuel is used in the engine maintenance area to conduct ground tests of engines after maintenance has been performed on them. Aircraft fuels charges are also incurred during functional check flights of aircraft. Since these check flights are often the final step in repairing an aircraft, the charge for the fuel expended on these flights is properly charged to the maintenance account.

E. MISCELLANEOUS INPUTS

The final major section of input categories is devoted to those miscellaneous expenses which are required costs of staying in business. These items can be thought of simply as overhead expenses, necessitated by the ongoing nature of the business. Table II provides a listing of the items contained in this category.

The "Cost of Sales" component seeks to group expenses associated with the external sales of maintenance services. Included in this component are the charges for insurance coverage, after sale service charges, warranty charges and any other direct cost associated with sales of maintenance services.

The "Miscellaneous Expense" component accounts for office supplies used at the facility and any inventory which has been paid for, but has not yet been received at the facility. Also in this grouping is the gain or loss experienced on items of flight equipment.

"Ground Equipment and Radio" refers to charges against the ground handling equipment, ground to air communications equipment, station security screening (luggage) equipment, etc.

The final grouping, "Facilities, Etc." picks up any other expenses such as property taxes and teletype services. Included in this section are any maintenance charges for the plant or buildings at the facility.

F. SUMMARY

The major categories described above (i.e. Labor, Material, Capital, Energy, and Miscellaneous) constitute the inputs which will be measured

TABLE II

MISCELLANEOUS INPUTS

I COST OF SALES

- A. COST OF SALES
- B. INCIDENTAL SALES EXPENSE
- C. PRODUCT LIABILITY INSURANCE
- D. WARRANTY RESERVE
- E. SALES OTHER
- F. CONTRACT SERVICES

II MISCELLANEOUS EXPENSES

- A. OFFICE SUPPLIES
- B. CONSIGNED SURPLUS
- C. GAIN/LOSS ON FLIGHT EQUIPMENT
- D. MISCELLANEOUS

III GROUND EQUIPMENT AND RATIO

- A. GROUND EQUIPMENT RELATED
- B. GROUND EQUIPMENT RADIO MATERIAL

IV FACILITIES/COMM/TAX/OTHER

- A. FACILITIES EQUIPMENT MAINTENANCE
- B. ADVERTISING & PROMOTION
- C. TELEPHONE & TELETYPE
- D. COMMUNICATIONS
- E. RADIO COMMUNICATIONS
- F. LEASED TELETYPES
- G. TRANSPORTATION
- H. PROFESSIONAL & TECH FEES
- I. OTHER SERVICES
- J. PROPERTY TAXES
- K. DAMAGE TO PROPERTY
- L. OTHER INJURY OR LOSS

and used to compute productivity measurements. Every attempt has been made to include all the possible input factors which go into making the aircraft maintenance evolution work. The deletions that have been made are considered minor and of no substantive value in the computations. The essence of the approach used was to isolate the aircraft rework facility from the parent corporation and then ask the question, "What services would the facility need to purchase or carry the costs for in order to provide the present level of maintenance services?" In this respect, the rework facility is visualized as a separate business concern, with the parent corporation and other airlines purchasing their maintenance services from the facility. It is important to keep this approach in mind when measurements of the outputs are performed.

V. THE OUTPUTS

Just as the measurement of inputs required extreme care, likewise the treatment of outputs must be carefully considered. The most important consideration in the treatment of outputs is to insure that all outputs are identified. Various types of business concerns generate vastly different outputs. Figure 3 provides a diagram of some typical outputs identified in a moderately sized manufacturing business.

The business of providing aircraft maintenance services generates its own unique set of outputs. The services provided at the facility are required to maintain the basic airframe, engines, associated components, and avionics of the parent corporation's airline fleet. Maintenance plans designed to ensure the integrity of the airframe and safety of the passengers are jointly prepared by the aircraft manufacturer, operators, and maintenance officials. The plans are subject to approval by the Federal Aviation Administration (FAA). Implementation of these scheduled maintenance plans constitutes approximately two-thirds of the work performed at the facility. [Ref. 9]

Major planned maintenance visits of the various type aircraft, both wide body and narrow body, take place approximately every 25,000 airframe flying hours. This is roughly equivalent to a service life expiration of a Navy aircraft. Heavy maintenance visits, roughly analogous to a standard depot level maintenance (SDLM) cycle, take place at 10,000 to 12,000 hour intervals for narrow bodies and at 14,000 hour

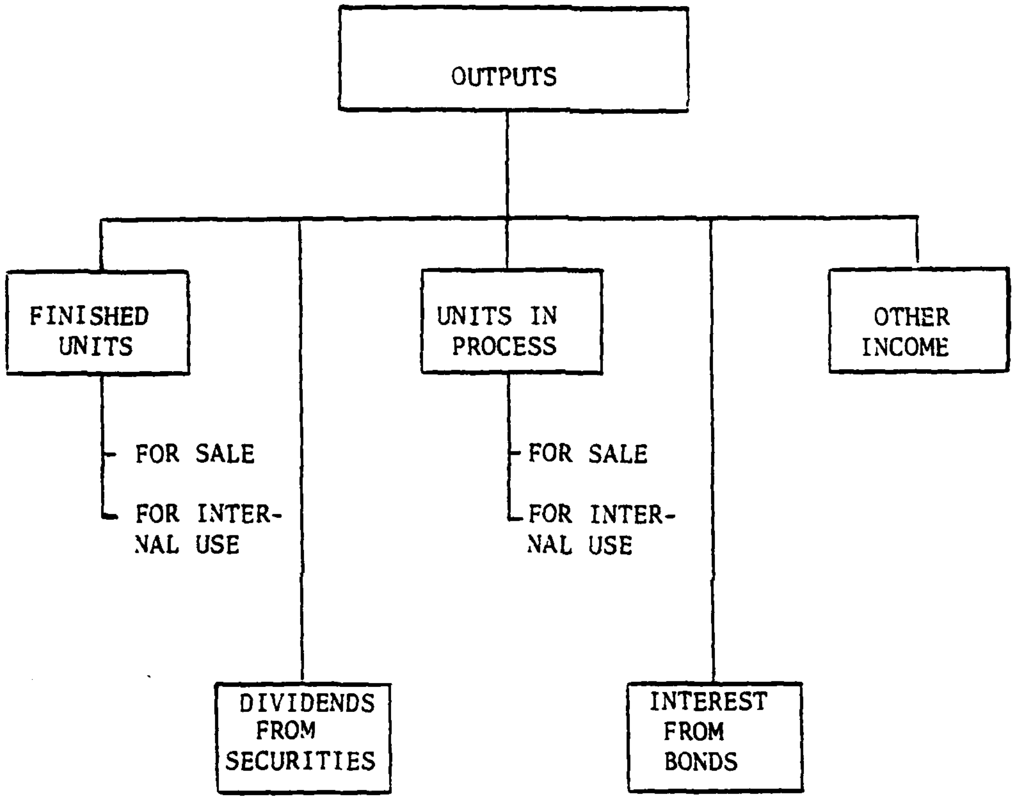

FIGURE 3. GENERAL OUTPUT ELEMENTS CONSIDERED IN A PRODUCTIVITY MEASUREMENT MODEL

intervals for the wide body aircraft. Simple phase checks, Navy equivalent to calendar inspections, are done every three to four months. In addition, other components which operate under high stress conditions, such as landing gear struts, are inspected according to their own particular maintenance plan.

Other work performed at the facility includes turbofan engine repair, component repair of items such as constant speed drive generator sets (CSDS) and hydraulic pumps, avionic repairs on pilot instruments and navigational equipment, interior cabin refurbishment, calibration of associated test equipment, and many other functions.

Converting these functions of output into dollars is an extremely difficult task. The work of the mechanics has increased the value of the airframe, as did the new parts and other materials that the mechanic used in the performance of his job. For example, the avionics technician repairs a radio. In the procedure of performing the repair, he applies his knowledge and experience by trouble shooting and isolating the problem. To correct the discrepancy, a new capacitor and inductive circuit are required. This new material is added and the technician finishes the repair action by making some final adjustments referred to as "peaking and tweeking." Not only does the mechanic's labor time add value to that radio, but the replacement parts have also increased its value. Since the vast majority of maintenance actions consist of these two elements, outputs can be defined in terms of labor and materials.

The problem of converting labor and material elements into dollars still remains; however, this partition allows discussion to proceed toward more fruitful ground.

A. THE LABOR OUTPUT ELEMENT

Throughout the literature on productivity measurement, the preferred output measure is man-hour equivalents. Since the point of productivity measurement is to measure the change in resources utilized for the production of physical quantities of goods, merely counting the number of automobiles, or tons of steel, or radios repaired, does no good. There is no basis for combining "apples and oranges." The answer lies in returning to the principle of equivalents; some unit which expresses the physical value of the product. Man-hours are the most appropriate units for developing a measure of the physical output of the firm. Such a measure is not affected by shifts in the market value of products, nor by changes in prices. [Ref. 5]

The measure is based on the principle of equating all products in accordance with the number of man-hours required to make each product. By using this method, all the various output forms can be easily equated. In other words, one earned hour of repairing radios is equal to one earned hour of painting the airframe.

The earned man-hour concept has been used at the rework facility since 1977. An internally developed output measure, designated to coincide with the earned hours of work required for two major jobs, has

in essence become the maintenance "product." All tasks performed at the facility are measured in terms of this "product," the Equivalent Maintenance Unit (EMU). The standard underlying the EMU is the man-hours required to perform the airframe maintenance check on the Boeing 727 aircraft and the engine overhaul for the JT8D-7 engine. Both these tasks, it was determined, require 1900 man-hours to complete. [Ref. 13]

Since all departments at the facility report their output in terms of EMU's, the labor output of the facility can be obtained from these records. EMU's can easily be converted into earned hours simply by multiplying the EMU total by 1900. In order to assign a dollar value to this output, some sort of average hourly labor rate must be found. The input labor rate could of course be a starting point in the search for this figure; however, this rate does not provide for any "value added." It is merely what the facility pays for its labor.

Perhaps a better figure to use as the output labor hour rate would be the contract sales price of labor. That is, the price the facility uses when it contracts out maintenance services to other airlines. Intuitively this is quite appealing. First, the contract sale of maintenance services represents a very small percentage of the total output at the facility. The bulk of the labor is expended in the repair and refurbishment of corporate assets. As such, the bulk of the labor is really provided "at cost" to the parent corporation. However, recall that in our attempt to isolate all the inputs, the approach used was to disassociate the facility from its corporate parent and base the input

figure on what goods and services were needed on site to provide the required maintenance activities. Using this same rationale of isolating the rework facility would require the corporation to pay the facility "market prices" for the services it provides. Therefore, assigning a contract sales value to the labor output would seem reasonable. Clearly the facility does not receive that much revenue; however, it is also not expending the entire amount called for under the input section.

The second shortcoming involved in using the contract sales price is just what this price is really paying for. The sale of maintenance services at the facility can be likened to the sale of excess capacity by a manufacturer. Normally this capacity is not really in excess, merely a temporary lull in the manufacturer's own demand. In one or two months the manufacturer will need all the capacity back for his own production. Rather than let this capacity remain idle during the lull, the facilities are contracted out. Whether the facilities are used or left idle, the <u>fixed</u> costs are still being incurred. If, by contracting out, the <u>variable</u> costs of operating the facilities can be paid for, the manufacturer has not really lost anything. This tactic is quite often used in industries where there is a heavy seasonal demand schedule.

At the aircraft rework facility the contract sales of maintenance services serves much the same purpose. The labor force remains stable since there is no need for seasonal layoffs and hirings. They remain active, performing the same maintenance actions on contract sales jobs

that are required on the corporation's fleet. The return from these contract sales provides extra revenue for the corporation. The problem being, what do the contract sales rates actually represent? Do these rates reflect just the variable costs of performing these maintenance functions?

The formulation of the contract sales rates does include some calculation of direct and indirect costs. Overhead rates are computed and provided to the contract sales division which detail variable and fixed overhead expenditures. Every single input factor is not considered in computing these overhead rates; therefore the contract sales rates are not "pure" rates for the performance of the maintenance. For the purposes of this project, the contract sales rates are representative enough to provide the necessary information. A final note on the output labor rates is that these rates and material mark-ups vary from customer to customer, depending on the specific work mix or content (see next section). The rates cited were average rates for the period under consideration.

Using the methods described above, both the quantity of the labor output and price of the labor output can be determined. The combination of the two results in the definition of the labor component of the output.

B. MATERIALS OUTPUT ELEMENT

Standard practice in most business concerns is to buy the materials necessary for a task and charge the customer a modest mark-up on the cost of that material. This mark-up can range from a few percent to

many times the original cost of the materials. In the aircraft maintenance business, the materials used range from bulk commodity items (such as paint, grease and fabric) to complex instruments and components (such as hydraulic pumps or generator sets). Bulk or commodity items usually are associated with a higher mark-up rate since more labor is added to these elements in order to provide a finished product. Subassemblies or semi-finished materials usually have a lower mark-up rate because most of the labor required to provide a finished product has already been added.

At the aircraft rework facility, the materials mark-up rate charged for contract sales varies from job to job. On a heavy maintenance check (including aircraft painting) the rate would be higher than, say an engine repair job. The rates charged for materials also determines the hourly wage rate charged to the customer; if the materials rate is low, then the labor hour rate would be slightly higher than average. The desired result is for both rates to cover the variable costs as part of the overhead associated with providing the services. The materials mark-up rates used in calculation of the materials output element are averages over manv contracts performed during the period of consideration. Once again the rate is applied to the total maintenance materials expense since the approach used in the project does not recognize the cost advantage of the parent corporation.

In addition to the basic materials mark-up rate which varies from year to year, the facility also charges its customers a flat mark-up

rate on maintenance services which the facility must have performed elsewhere. For example, say the Boeing 747 main landing gear strut cannot be reworked with the existing facilities at hand, These struts are then contracted out, to Menasco, for the rework job. When returned and installed on the contract aircraft, the facility charges a fifteen percent mark-up on the cost of that rework. These so-called "purchased maintenance" charges for contract sales and regular corporate fleet work are kept in a separate account and can be easily identified. The sum of the purchased maintenance charges plus the mark-up and the maintenance materials plus the mark-up constitutes the total materials component of the output.

C. SUMMARY

Calculating the output of an aircraft maintenance facility involves visualizing the output as composed of two different elements. First is the labor element. This element consists of the many diverse tasks performed by mechanics, supervisors, planners, and other personnel at the facility. Measuring each of these tasks and equating one to another posed a unique problem. The answer to measuring the labor output element involved converting each task into a man-hour equivalent. In this manner each could be measured and equated. Putting a dollar value to these labor quantities involved the use of average contract sales hourly labor rates. Some minor discrepancies involved with using this method were recognized and discussed. The decision was made, however,

to pursue the use of this method, even with these shortcomings. The information provided from the model, even inexact as it may be, is better than no information at all.

The second output element recognizes the contribution of materials to the maintenance task. Since all business concerns utilize some sort of mark-up system on the materials they use to produce goods and/or services, this element of output was fairly simple to visualize. The materials element consists of two sub components: regular maintenance materials and so-called "purchased maintenance." The regular maintenance materials mark-up rate was derived by obtaining an average from the various contract sales jobs performed at the facility. The "purchased maintenance" refers to certain tasks which are contracted out by the facility. These tasks are ones which involve certain skills and equipment not available at the facility or reflect an overload of work at the facility itself. A straight mark-up rate over cost is used here. The total material element is then composed of the regular maintenance materials expense plus the mark-up and the purchased maintenance plus its mark-up.

The combination of the labor and material output elements provides the APC model with its measurement of the facility's output. The final product of an aircraft rework facility is of course an aircraft ready for flight. However, in order to ready one aircraft for flight, thousands of individual tasks must be accomplished. It is the measurement of these individual tasks which, for this project, constitutes the true

"product" of the facility. Figure 4 provides a graphical look at the outputs of the aircraft maintenance facility.

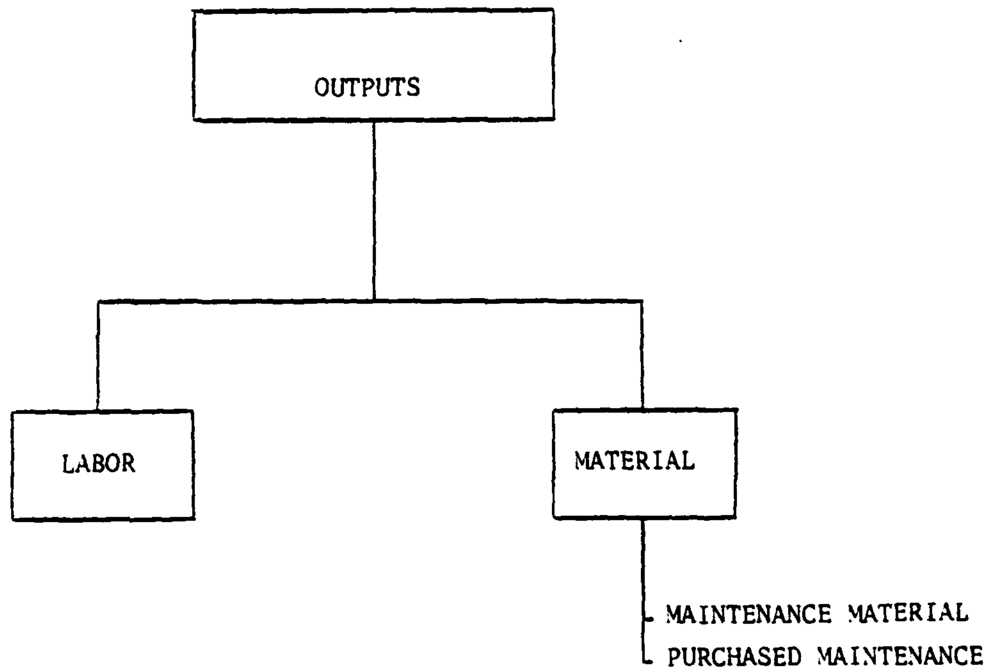

FIGURE 4. OUTPUT ELEMENTS CONSIDERED BY THE AMERICAN PRODUCTIVITY CENTER MODEL

VI. FIELD TEST AND RESULTS OF THE APC MODEL APPLICATION

In the preceding chapters a productivity measurement model has been advanced and tailored around the task of measuring productivity at a large aircraft rework facility. The acid test of this development is, of course, the actual application of the model to "live" data. Before this can take place, however, a base year must be determined. Under ideal conditions, the selection of a base year would attempt to isolate a year which is basically representative of "normal" operations. In this manner, comparisons to the base year can accurately reflect deviations from normal operations. For the purposes of this project, the base year was selected to be 1977. Unfortunately the reasons for this selection are not those associated with "ideal conditions." The year 1977 was selected due to data availability. Recall that the rework facility began collecting output product information in 1977; therefore 1977 was selected. In defense of this selection, 1977 does seem to exhibit "normal" operations; thus 1977 can be used as the base year without reservation.

The data necessary to perform the required calculations was transcribed from the facility's operating expense reports according to the criterion set forth in Chapters IV and V. For the years 1977 and 1978, the data for the entire year was immediately available. Reports from the year 1979, however, reflected a short year of operations due to a work stoppage. This required that some sort of estimation process be

employed to round out the 1979 data. The method utilized involved the use of the actuals plus some planned data for the period of the stoppage. These planned figures, prepared quarterly and published in advance of the period under consideration, are used by planners and management for the purposes of administering the facility. As such, the figures provide a reasonably accurate picture of the actual data. For the current year, 1980, the first nine months' actual data was available. This data, augmented by the last quarter's planned data, provides the 1980 data.

All the data having been collected, preparations were made to perform the necessary calculations; however, two discrepancies surfaced. First, the facility incorporates a labor improvement factor into the output measure (the EMU). This factor is designed to account for the increased productivity attributed to throughput and learning curve considerations. The second discrepancy involved the relationship between current year and base year inventory and materials values. Since no pure-quantity relationship exists, the question of comparing current year inventory and materials against base year inventory and materials becomes an issue.

A. THE LABOR IMPROVEMENT FACTOR

In order to account for productivity improvements due to learning curve considerations, the labor improvement factor is built into the EMU accounting process. This improvement factor is indexed in terms of a 1977 base, resulting in the labor improvement factor for 1977 being unity. The improvement factors used by the EMU system are listed in Table III.

TAB[illegible] III: LABOR IMPROVEMENT FACTORS 1977-1980

YEAR	LABOR IMPROVEMENT FACTOR
1977	1.00
1978	1.026
1979	1.041
1980	1.115

In essence the inclusion of the labor improvement factor says that a recorded EMU count of 100 in 1980 is really equivalent to 111.5 EMU's (in terms of actual work performed to 1977 standards). Realistically, however, the output product which generates revenue is the recorded value of 100. The question is, which value of output should be used in the calculation process?

The decision regarding how to treat the labor improvement factor hinged on two points. First, the quantity which generated revenue for the facility must be included when performing the $Q_2^U P_2^U$ computation. Second, a computation which required that the quantities be indexed with 1977 prices, the $Q_2^U P_1^U$ term, requires that the Q_2^U term accurately reflect the amount of output which would have generated labor. Consequently, in the computations involving a relationship between current year quantities and base year prices, the $Q_2^U P_1^U$ term, the Q_2^U term is stated in terms of the 1977 standards. In other words, the labor improvement factor for the year under consideration is multiplied by the recorded EMU figure, yielding a current year quantity in terms of 1977 standards. This term reflects the value of 1980 (for example) labor output priced out at 1977 prices.

Any of the computations in which it is required to express a relationship between current year quantities and prices, the recorded EMU data was used. That is, where the term $Q_2^U P_2^U$ appears, the Q_2^U is stated "as is" from the recorded EMU data.

This treatment of the labor improvement factor is consistent with the goals of the APC model. Since the improvement factor attempts to "discount" labor productivity improvements due to learning curve factors, the measurement process should recognize this "built-in discount." At the same time, the model must also recognize the actual revenue returns from the ouput products. The methodology devised for the treatment of the labor output data allows both factors to be considered.

B. INVENTORY AND MATERIALS VALUATION INDEX

A second discrepancy noted in the collected data also involved the computation of the $Q_2 P_1$ both on the input and output side. Without an expressed price-quantity relationship, the values assigned to the inventory and materials cannot be discounted from their current year values to a base year value. To be sure, at a microscopic level, some sort of price-quantity relationship exists; however, at the macroscopic level of the APC model, that relationship becomes far too complex to handle. Computations involving the input or output $Q_2 P_1$ terms for inventory and materials becomes exceedingly difficult.

One possible solution would be to simply ignore the problem, that is, when computing the input or output $Q_2 P_1$ term, simply use the current year material and inventory values. In reality this "solution" is

short-sighted and does not attempt to recognize inflation and general price escalation. A better solution would be to try and index the inventory and material accounts in terms of 1977 constant dollars. If such indexing were possible, the $Q_2 P_1$ term for each year could be easily calculated for the inventory and materials accounts.

Fortunately, inventory data reflecting actual dollar amounts for total inventory and 1976 constant dollar amounts for total inventory were available from the inventory accounts section. This enabled a deflating factor to be computed which allowed the inventory and materials accounts to be expressed in terms of 1977 dollars. Table IV presents the inventory and materials value index used to compute the input and output terms involving materials and inventory.

TABLE IV: INVENTORY AND MATERIALS VALUE INDEX

YEAR	ACTUAL $ (MILLIONS)	CONSTANT $ (MILLIONS)	% CHANGE	VALUE INDEX
1977	362	357.5	1.012	1.0
1978	344	332	1.038	1.026
1979	337.5	314.5	1.073	1.06
1980	348	310.5	1.121	1.108

The inventory figures used in Table IV reflect not only the book value account detailed in Chapter IV, but the reserve accounts as well. Recall that the reserves and book value accounts represent the true replacement cost of the inventory.

C. RESULTS FROM THE MODEL APPLICATION

The next step in the measurement process is to actually perform the desired calculations. Appendices A-2 through A-4 tabularize the collected data in the format necessary to perform these calculations. The "actual" data, (Q_2 P_2) and the "deflated data, (Q_2 P_1) are presented for ease of understanding and clarity. Calculation summaries are presented in Appendix B for the Productivity Index, Appendix C for the Pricing Recovery Index, and Appendix D for the Cost Effectiveness Index. Figure 5 is a graphical presentation of these results. Variance calculations and results are detailed in Appendix E.

While specific recommendations and conclusions will be made in the final chapter, some basic observations regarding the results are in order. First, the results graphed in Figure 5 point up an interesting situation. The Productivity Index, after remaining constant from 1977 to 1978, has been steadily increasing from 1979 to the present. At the end of 1980, productivity has improved to slightly more than four percent over the 1977 index. Contrasting the productivity increase is the steady <u>decline</u> of the Pricing Recovery Index. By 1980 this index is almost eight percent <u>less</u> than the 1977 standard. The Cost Effectiveness Index, while declining from 1977 through 1979, has shown a modest improvement in 1980. Recall that the Cost Effectiveness Index, in reality a profitability indicator of the firm, is the product of the Pricing Recovery and Productivity Indices. This explains the slight recovery in 1980, since productivity increased so dramatically so as to offset the drop in pricing recovery.

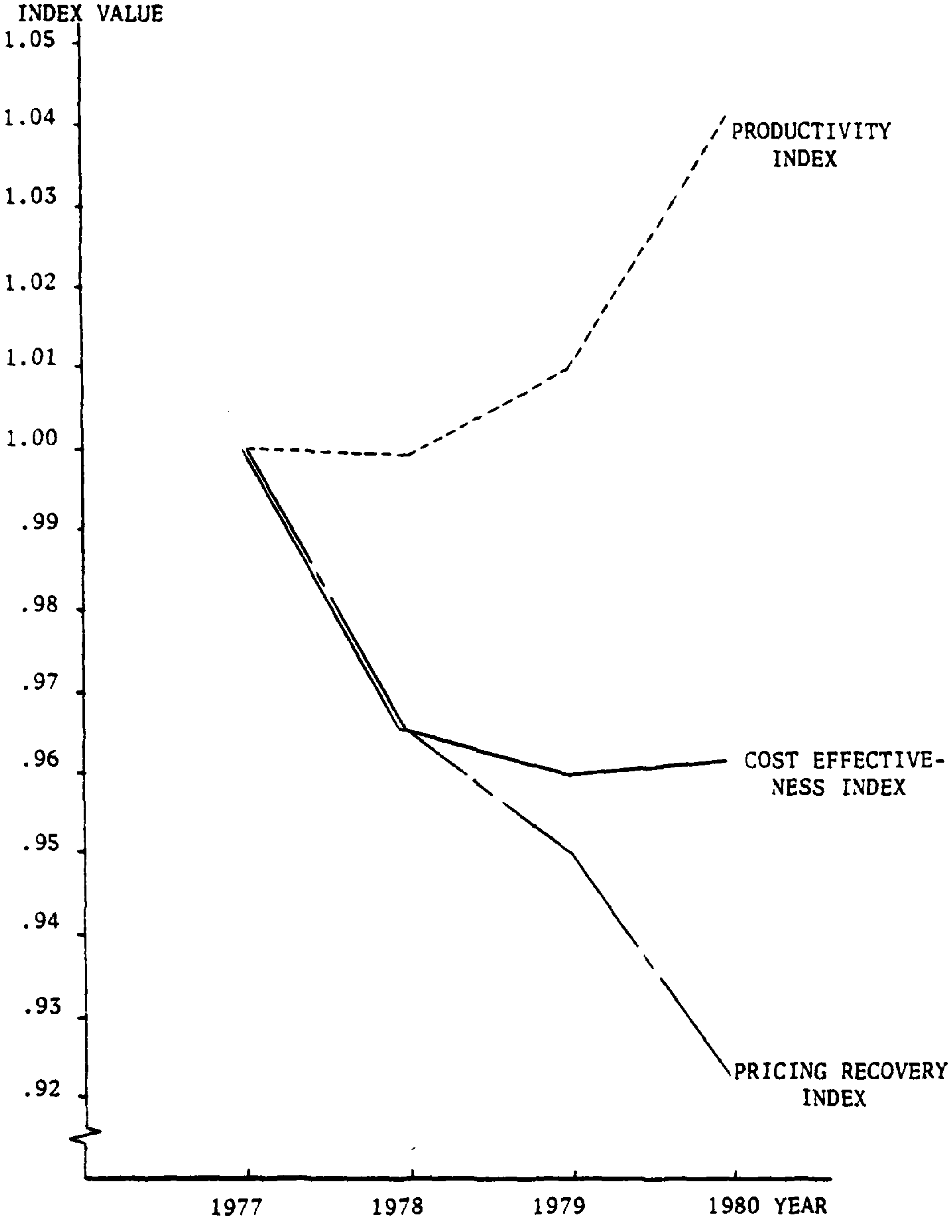

FIGURE 5. AMERICAN PRODUCTIVITY CENTER MODEL RESULTS

The variance calculations and results also demonstrate interesting trends. With the Pricing Recovery Index steadily declining from 1977 through 1980, the Pricing Recovery Variances also display a steadily declining performance. In particular, the Labor Pricing Recovery Variance is reaching alarming proportions. By 1980, it has reached a negative twenty million dollars and is growing at an annual rate of six to seven million dollars. In contrast, the Productivity Variances are demonstrating strong performances; the Labor Productivity Variance in 1980 is some nine million dollars better than standard.

D. INTERPRETATION OF THE RESULTS

Perhaps the best way to gain some understanding of the results is to review the basic definitions of the indices and variances. In this manner, not only does the meaning of the numbers become clear, but also possible conclusions may begin to form.

Recall from Chapter III that the Productivity Index relates quantity ratios in the current year to quantity ratios in a base period. The intent here is to measure the physical composition of the output-input ratios in each period. The Cost Effectiveness Index, the profitability indicator, relates changes in costs to sale revenue. Finally, the Pricing Recovery Index relates the price ratios of outputs to price ratios of inputs. Basically this index demonstrates how well the firm has been able to absorb increased input costs, and thus combat inflation.

The individual variances give an additional insight into the parent indices. The Cost Effectiveness Variances (C_1) indicate the contribution

of a particular resource to the firm's overall profitability. The Productivity Variances (C_2) demonstrate how each resource is performing in regard to the firm's production efficiency, while the Pricing Recovery Variance of each resource indicates how well the firm has passed on the increasing costs of resources to its output products.

Reflecting on these definitions, the results of the model calculations begin to make some sense. Perhaps the most readily observable fact is that the Pricing Recovery Index is declining at far too rapid a rate. The facility seems to be absorbing the increased input costs without revaluing its output. The variances for pricing recovery indicate that labor input costs are the primary cause of this decline. On the other hand, as the Productivity Index increased, that increase was largely due to improvements of labor and materials; a relationship that should come as no surprise since these are primarily the areas in which learning curve growth takes place.

The final observation to be made relates to the firm's overall profitability or cost effectiveness. The information indicates that, in terms of a 1977 standard, the firm in 1980 is slightly less than four percent less profitable. The reason is, as can be seen from the graphs on Figure 5, not a reduction in productivity, but increases in the input prices which are not adequately distributed to the output product.

E. SUMMARY

In previous chapters, the methodology used in this project for measuring productivity has been presented. Utilizing this basic outline,

data was collected in preparation for making the calculations of the APC model. Prior to the performance of these calculations, two discrepancies were noted in the collected data. The first involved the use of a labor improvement factor, which is built into the EMU collection process in order to discount the effects of learning curve improvements in productivity. Second, the values assigned the inventory and materials accounts were stated in terms of current year dollars. Since no price-quantity relationships exist for these accounts, computations indexing current year quantities to base year prices were seemingly out of the question.

At the basis of both discrepancies were the computations which require current year quantities (C_2) and base year prices (P_1) to be totalled up. The solutions for both problems required that this root problem be recognized. Understanding just what the calculations involved made designing appropriate "fixes" much easier. Thus, having at least reached the point where calculations could be performed, that process was undertaken.

The results, including calculation summaries, are detailed in the Appendices. The most readily observable result involves the startling decline of the Pricing Recovery Index and its associated Pricing Recovery Variances. Secondary to this observation is the effect this decline has on the overall cost effectiveness or profitability of the facility.

VII. REVIEW

A. GENERAL INFORMATION

Productivity is a topic in which every manager should have a vested interest. In today's economic climate, productivity is perhaps the only weapon of note which can be successfully used against inflation. The project undertaken by this study is to develop and apply a total productivity measurement model to a large commercial aircraft repair facility. With the success of the measurement model, great strides can be made toward productivity improvement.

However, the task of measurement is not as simple as it first would appear. In order to measure some quantity, first the quantity must be recognized and defined. The question becomes, "What is productivity?" In this relatively new field of endeavor, getting two "experts" to agree on something as basic as the definition of productivity can be viewed as a major breakthrough. What almost all experts will agree to is that the productivity problems of this country are due in no small way to the lack of understanding surrounding the concept. If productivity at the aircraft repair facility is going to be measured, a common definition of just what productivity really is must first be formulated.

Although different people express different ideas of productivity, the common thread which weaves through all definitions involves the "...efficient and effective use of available resources." The definition of productivity used for the purpose of this project stresses that concept and the idea of <u>total</u> productivity. Productivity can be defined as

the measurement of economic and human effectiveness on the basis of real output per unit of resource consumed. The use of this particular definition, however, requires that the term "productivity measurement" also be defined.

In concept, to measure productivity, a ratio of outputs over inputs must be taken. In fact, such a ratio is a very difficult relationship to obtain. Productivity measurement then is that process of relating outputs and inputs in such a manner as to obtain an output unit per input unit.

The study of productivity is an outgrowth of the field of economics; however, not until the late forties were statistics and data on national productivity available in quantity. In this country, long known for its staggering capacity to produce, productivity study has been given much lip service. Abroad, however, the United States Government has encouraged and even financed international productivity study centers. In postwar Europe and Japan, these centers were formed as a result of U.S. Government financing. Although not financed by U.S. dollars today, both West Germany and Japan continue these productivity centers and have reaped the rewards of their insight. The United States finally formed its first national productivity study group in 1970.

The airline industry has long been a leader in productivity improvements. [Ref. 11] However, in recent years, the rate of improvement has been slowing. At a large commercial carrier's repair facility, management has been interested for some time in a program aimed at improving

productivity. This project is merely a continuation of that program with the aim of developing a productivity measurement model capable of being applied to the entire facility and its operations. The magnitude and breadth of repair work performed on large transport aircraft is staggering. To somehow translate the myriad jobs, tools, products and energies involved in maintenance into coherent inputs and outputs is indeed a big job.

B. THE MODEL

Chosen for the task of measuring productivity at the facility is an adaptation of the American Productivity Center's Total Factor Productivity Model (APC Model). Prior work at the facility has been done using this model and management is familiar with its mechanics. The model is quite simple in structure, yet it provides the decision maker with powerful information. As is the case with most of the current productivity measurement models, the format involves the computation of three indices which relate performance between two operating periods. The three indices used by the APC model are:

(1) Cost Effectiveness Index - value ratios of outputs to value ratios of inputs for the two periods under consideration, reflecting how costs in the current period compare with cost relationships (outputs to inputs) established in the base period.

(2) Productivity Index - Quantity ratios in a current period to ratios in a base period demonstrating the change in quantities over the two periods.

(3) Pricing Recovery Index - relates price ratios of outputs to price ratios of inputs showing to what extent the firm has been able to absorb the increases in prices of inputs.

In addition, the APC model allows for the calculation of variances relating to the indices. These variances basically relate to the extent each input factor has contributed or hindered the overall goal achievement of the firm.

The APC model is not designed to require additional paperwork or accounting data. The majority of the information needed by the model should be readily available from standard accounting reports. Indeed, one major complaint of many management personnel is that too often a productivity measurement system requires a complete realignment of corporate accounting structure and reports. The APC model, on the other hand, is designed to complement the current accounting system data.

The key feature of the APC model is that it relates productivity directly to profitability. Cost Effectiveness is really the product of the Pricing Recovery and Productivity indices. The definition of cost effectiveness reveals it to be, in reality, an index as to the profitability of the firm. The direct relationship between productivity and profitability often surmised by managers is presented on paper as mathematical fact.

C. THE INPUTS

Determination of factors to be used as inputs in the aircraft maintenance process is no easy task. In addition, some sort of common unit of

measure must be found. Since the model calls for the use of dollars as the unit of measure, the problem of a common measure vanishes. However, a source of input data must still be identified. Fortunately, most business corporations keep detailed records of their expenditures during a period of operations. For this project, the facility's operating expense reports were used to provide the detailed input information necessary.

As to the decision of what factors should be included as input information, the approach used was to "divorce" the facility from the parent corporation. In other words, consider the facility as a business unto itself. The goods and services necessary for the facility to provide the same level of maintenance operations can thus be classified as the "Inputs" of the model. These inputs are labor, material, capital, energy, and a miscellaneous category.

The labor category of the inputs means all personnel employed by the facility. It is unfortunate that the term "labor" has taken on the meaning of unskilled or semi-skilled workers. Indeed these two types of workers are needed in an aircraft maintenance facility; however, so are the certified mechanics, inspectors, supervisors, engineers, and accountants. In order to measure the labor input, the unit of man-hours has been chosen since, with an average labor rate (dollars per hour), this can be easily converted into the desired dollar equivalent. Since there exist two man-hour measures, "hours paid for" and "hours worked," a selection was necessary. In this project, labor has been stated in terms of

"hours worked" since it more accurately reflects the labor applied to aircraft and this data was available through the accounting records.

The materials portion of the input function was perhaps the easiest category to obtain. This data was extracted directly from the operating expense reports. Not only does materials include specialized assemblies such as hydraulic pumps, it also includes such bulk materials as grease, oil and cloth for seats.

Capital is perhaps the most difficult input category to isolate, yet one which can have the most far reaching effects on productivity. There exists no "universally accepted" method of computing the capital component, In fact, a number of methods exist. Perhaps the most appealing treatment of capital is to view it from the standpoint of a depreciation charge or a lease value. That is, what costs paid in the form of lease payments or rents would the facility incur if it did not own the buildings, plant, machinery, special tools, etc. This treatment, although loaded with flaws, also gives a capital figure in terms of an annual operating period.

In addition to the depreciation charges against fixed assets, another component of the capital input category is the working capital expense. In the case of the aircraft maintenance facility, the only working capital input would be the inventory account. To obtain the working capital portion of the capital input, the formula used was to multiply the inventory book value and the corporation's average cost of capital. This is intended to represent the capital cost incurred by the facility since

it is investing in materials (inv y account) rather than some other available investment.

The energy costs incurred by the facility can be easily broken out using a detailed version of the operating expense work. The energy category is broken down into three components: electricity, natural gas, and aircraft fuel.

The final input category is basically a "catchall" full of miscellaneous charges necessary for the facility to stay in business. Components of this category include Cost of Sales, Ground Equipment and Radio, Facilities Maintenance, and Other expenses.

D. THE OUTPUTS

The problem of properly identifying outputs is perhaps an even greater challenge than identifying inputs of the aircraft maintenance process. The myriad of jobs performed on a single airframe defies comprehension. Clearly the "output" of a maintenance facility is maintenance services. The question becomes one of measuring these services in such a manner as to properly account for each one. In order to do this, two categories of outputs must be recognized. First is the labor aspect; that is, the value added to the airframe by the mechanic performing various jobs. Second is the material aspect in that almost every job requires the mechanic to install new or rebuilt material. The output of the aircraft maintenance facility can then be accounted for using these two categories.

Having broken the output into two categories, how does one measure the labor portion? The answer lies in the use of man-hour equivalents, or

earned-hour concept. The earned hour concept of measuring labor output is not new at the facility. In 1977, a program for measuring earned hours and collecting this data was created. Indeed, the measure of output (labor) used at the facility corresponds to the man-hours required to perform the airframe maintenance check on the Boeing 727 aircraft and the engine check on the 727's JT8D-7 engines. All departments at the facility report their labor output in terms of these standards, or as they are called Equivalent Maintenance Units (EMU).

In order to value the labor output data collected in EMU's, the contract sales rate for labor was used. This associates a dollar figure with each hour of labor when the facility performs maintenance on aircraft other than those of the parent corporation. This formula, EMU converted to earned hours times the average contract sales rate of labor, provides the dollar figure for the labor portion of the output.

The second category of outputs is materials. Again the use of the contract sales for material mark-up is used to assign a dollar figure. The materials to which the mark-up rate is applied include all materials used in the performance of maintenance functions. Exempt from this mark-up are so-called "purchased materials" which correspond to goods and services that, for one reason or another, the facility contracts out. These purchased materials are marked up at a standard rate of fifteen percent. The materials category of output is composed of the total of materials times the mark-up plus purchased materials times the standard mark-up.

E. THE RESULTS

Having fleshed out the structure and procedures to be followed in the actual measurement process, only data collection and final calculations are needed to complete the project. After data collection, however, two minor discrepancies were noted. Both are centered on the computation of the $Q_2^U P_1^U$ terms used to compute the Productivity Index and the Pricing Recovery Index.

The first discrepancy involves the use of a labor improvement factor which is automatically factored into the EMU collection process. This factor, in a sense, accounts for increased productivity, due in part to benefits from learning curve factors. The EMU total in 1980, if it were restated in terms of 1977 EMU's, would be higher by a factor equal to the labor improvement factor. The question becomes which labor quantity should be used; the raw EMU count, or the EMU count factored by the labor improvement factor?

The answer chosen involves actually asking if the model should account for labor productivity improvements due to learning curve considerations, and examining what the $Q_2^U P_1^U$ term actually means. It was decided that a product'vity measurement model should in fact show the productivity increase due to any learning curve considerations. In addition, the $Q_2^U P_1^U$ term should accurately reflect the current year quantity factored out at the base year price. Unfortunately, the Q_2^U term does not accurately reflect the true quantity needed in terms of 1977 labor. Therefore the raw EMU count should not be used, rather the EMU count

factored by the labor improvement factor should be used. Thus in any situation where the $Q_2^U P_1^U$ relationship is being used, the Q_2^U term used is the EMU count factored by the labor improvement factor. Elsewhere the raw EMU count is used.

A second discrepancy, much along these same lines, involved the use of materials value on both the input and output side. Since only a dollar value is given for materials, and no price-quantity relationship exists on the macro level, the question becomes: Can the Q_2P_1 term be accurately calculated? In order to "deflate" the materials charges against the base year and preclude this question, a relationship between the inventory accounts was calculated. This ratio effectively deflated the materials value into 1977 constant dollars for use in any computations involving Q_2P_1 terms.

Having disposed of the last two discrepancies, the calculations required by the APC model were performed. These calculations are summarized by Appendices A through E. The results indicate some interesting facts.

First, productivity seems to be rising although pricing recovery is steadily declining. Cost effectiveness, the overall profitability indicator, is down from the 1977 standard; however, it is making a modest recovery. Figure 5 displays a graph with all three indices mapped out over the period of consideration, 1977-1980.

The results in hand, the final chapter of this report will deal with the analysis and any recommendations which need to be made. It is helpful

here to remember that productivity measurement is only one link in the productivity improvement cycle. In order for the measurement process to be of any use at all, the results must be carefully considered and acted upon. Without any action, there can be no productivity improvement.

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

(1) Perhaps the first conclusion is that the results obtained can be supported by reality. Over the period of the measurements, the facility's Productivity Index has been rising. During that same period the parent corporation has been modernizing its fleet of aircraft. This modernization program, as well as other factors, would tend to support an increase in productivity since new aircraft require less extensive maintenance than older models. That is, a similar number of checks would be performed on both a new airframe and an older airframe; however, an older model would very likely require much more secondary work. Checks in the newer aircraft would proceed much more smoothly and would be accomplished more efficiently.

Over this same period (1977-1980) inflation has been proceeding at a double-figure rate. It has been extremely difficult for companies to keep abreast of these inflationary pressures. The behavior of the Pricing Recovery Index reflects such a trend at the facility.

(2) The APC model, as developed in these pages, provides the facility with a procedure for evaluating not only its productivity, but also its pricing decisions and overall facility profitability. The detail used in the preceding chapters had purpose in that this project is designed to be continued and further refined. Such a task requires that a clear audit trail be left so that those who continue this research will not have to retrace these steps. In just a few months, 1981 planned data

will be available at the facility. Using this methodology, a "sneak preview" of 1981 performance can be had with plenty of time left for adjustments or corrective measures. Because the model ties together productivity cost effectiveness, and pricing decisions, the manager gets a real sense of what the implications are of the decisions in these areas.

(3) The relationship between the Productivity Index and the Pricing Recovery Index makes it quite clear (see Figure 5) that the facility is not keeping pace with inflation at all. The steady decline of the Pricing Recovery Index indicates that input prices are rising and the output prices have not been adjusted to compensate for this rise.

The conclusion here is that the overall profitability of the facility is suffering as a result of pricing decions rather than productivity problems. In fact, productivity has cut into the pricing losses, otherwise the profitability performance would be even worse.

(4) Analysis of the variance results leads to the conclusion that the pricing decisions involving labor have contributed most to the negative performance of the Pricing Recovery Index. The meaning of this is that, while input rates for labor are going up, the rates charged on the output side are not reflecting those increases. In other words, the facility is paying more for the labor which is employed; however, the rates which are used to sell that labor are not recouping these increases; consequently, the facility is operating at a less profitable level than the 1977 standard.

B. SENSITIVITY ANALYSIS

The above conclusions were all based on the model results and assumptions outlined in previous chapters. Chief among those assumptions was the believability of the labor improvement factor. Recall that in Chapter VI, the term $Q_2^U P_2^U$ was computed using the current year EMU count factored up by the labor improvement factor. For the sake of argument, suppose that the labor improvement factor was suspect. That is, suppose management at the facility has real doubts about the validity of an increase in productivity, of eleven percent in 1980, due to learning curve and other factors. As a form of sensitivity analysis, let us examine what the results would be if the raw EMU count is used throughout the model calculations. Appendix F provides a summary of the index calculations and Figure 6 gives a graphical display of these results.

Under this set of assumptions, the facility's overall profitability, or cost effectiveness, remains exactly the same as before. Cost effectiveness is below the 1977 standard; however, during the past year, 1980, it has demonstrated a modest recovery.

The Pricing Recovery Index and Productivity Index demonstrate slightly different behaviors however. With the reduced labor output, due to the absence of the labor improvement factoring, the Productivity Index is hovering slightly below the 1977 standard, rather than exhibiting the dramatic increases as before. The Pricing Recovery Index is still far below the 1977 standard; however, rather than demonstrating a steadily decreasing behavior, it is leveling.

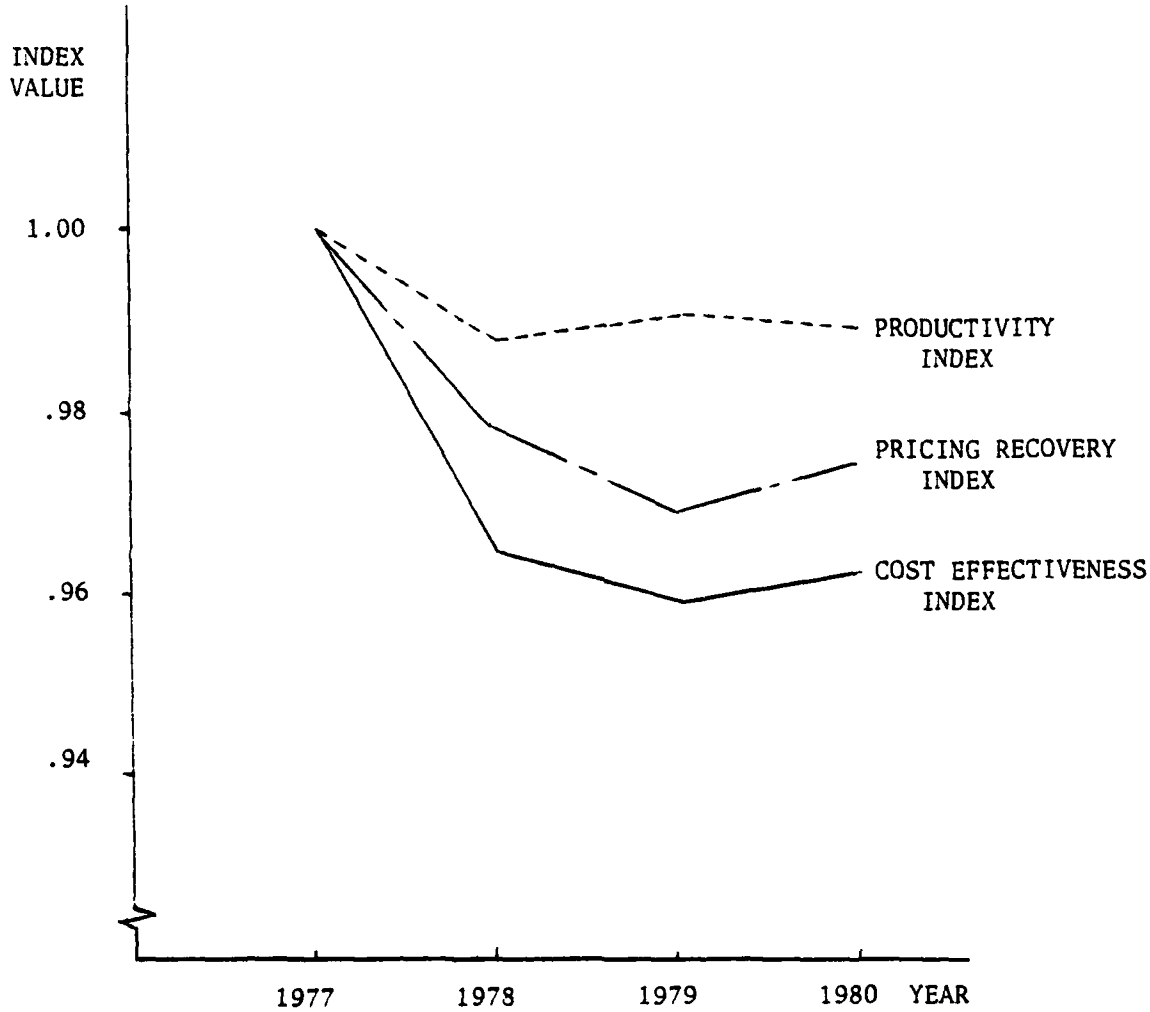

FIGURE 6. APC MODEL RESULTS WITHOUT LABOR IMPROVEMENT FACTOR

Such a leveling behavior of the Pricing Recovery Index might be more in line with the background information available on the pricing decisions of the facility. Recall from Chapter V the pricing decisions at the facility are made not on a total cost allocation basis, but on a marginal costing basis. Since prices used to sell the output do not cover all of the fixed costs, the Pricing Recovery Index could never rise above unity; yet if the variable costs are accurately covered in the rates used by contract sales, the index would be more or less constant at some value less than the 1977 standard. Recall also that the 1977 index is artificially set at unity; therefore the drop from 1977 to 1978 is not significant.

Viewing these results, management could indeed question the validity of the labor improvement factor. Perhaps the value of the labor improvement factor is more suspect than the theoretical basis of the factor. Learning curve factors are indeed a source of productivity increases; however, learning curve influences are not as pronounced in a job shop operation, such as aircraft maintenance, as in a production line climate. Therefore it may be possible that the labor improvement factor is overstated.

One thing is quite clear, the performance of the indices in either scenario (with or without the labor improvement factor) is slightly different; yet the overall relationship to profitability expressed in each case is the same. Productivity is either very close to, or better than, 1977 standards while Pricing Recovery is, in both cases, less than

the 1977 standard. The implication is clear; pricing decisions, rather than losses in productivity, have caused profitability to decline.

C. RECOMMENDATIONS

(1) First, given the relationship between Pricing Recovery and Cost Effectiveness, either with or without the labor improvement factor, recommend an examination of the contract sales rates. These rates are not reflecting the increases of input prices, and thus the facility's profitability is suffering. The contract sales rates are formulated based on direct and indirect cost computations. The answer possibly lies in the categories of costs collected for contract sales rates and those collected as inputs for the model. Perhaps the model includes some categories of costs in its computations that the contract sales do not. Further, perhaps the contract sales rates should include these added categories.

Realizing that the facility competes in a market place, perhaps the contract sales rates are constrained by this factor. That is, the facility charges what the market will bear, yet this charge does not allow for profitable operations. The facility is in competition with other providers of maintenance services, some of which are not as large. These smaller operations can operate profitably on the current rates since they have reduced overheads and lower fixed costs.

Also the facility may incur additional costs due to inventory and tooling which is maintained due to a decision by the parent corporation.

For example, if the facility were a profit motivated operation, it would only hold ten spare "black boxes." However, since the facility is primarily in business to support the parent corporation's fleet, the parent corporation requires that thirty spare "black boxes" be maintained in the inventory. These added costs serve to increase the facility's overhead base and make it more difficult to operate effectively.

The first recommendation would then be to examine the formulation and composition of the contract sales rates in the context of any real world restrictions (such as the prevailing market price) with a view toward increasing the output price rates.

(2) A second recommendation to review the procedures used to establish the labor improvement factor must be made in view of the results obtained in the sensitivity analysis. In addition, the variance results in 1980 (Appendix E) are of significant enough value as to require some investigation. Variances are a real double-edged tool in that too negative a contribution can also indicate a discrepancy. Again, the theoretical basis of the labor improvement factor remains sound; however, the methodology used to arrive at a numerical value from year to year should be reviewed.

(3) The final recommendation involves the continued research and refinement of this model. The variances computed in the APC model are the key to future improvements. These variances isolate the areas of greatest concern and effectively prioritize remedial actions. For example, given the variance results in Appendix E, the first area of concern

would be the labor pricing decisions, since that variance is on the order of negative twenty million dollars. The recommendation then would be to continue the research and use of the APC model with particular attention and emphasis on the variance results. Further, it is recommended that some additional research be done on the topic of variances in order that the information which is contained in these results be properly used.

D. SUMMARY

The conclusions and recommendations reached in this project are presented here in abbreviated form.

<u>Conclusions</u>:

(1) The results bear out the facts of real world operations.

(2) The model as it has been developed gives management a "canned" method of viewing the results of its decisions as they impact productivity, pricing, and profitability.

(3) The facility is rapidly falling behind in the battle against inflation, as evidenced by the steadily declining Pricing Recovery Index. Overall profitability is also adversely affected by this decline.

(4) The negative performance of the Pricing Recovery Index seems to be largely the result of a strong negative contribution of the labor pricing decisions, evidenced by the labor pricing recovery variance.

<u>Recommendations</u>:

(1) Recommend an examination of contract sales rates in an effort to stem the steady decline of the Pricing Recovery Index.

(2) Recommend a review of the procedures used to arrive at the numerical value of the labor improvement factor given the labor productivity variance and results of the sensitivity analysis.

(3) Continue the use of the APC model with further research and refinements, especially in the areas of the variance computations, for it is here that the productivity improvement actions take form.

APPENDIX A-1

1977

INPUTS ($ 000) except as noted		Actuals (Q_2P_2)			Deflated (Q_2P_1)
Actual hours worked	(000)	15,524			N A
Hourly wage	($/hr.)	13.53			
Personnel expense				210,051	
Personnel related				652	
Maintenance Materials		145,137			
Cost of Sales		2,637			
Miscellaneous		805			
Ground equip & radio		143			
Fac/Comm/Tax/Other		9,278			
Energy					
Electrical usage (KWH)	(000)	101,650			
Rate ($/KWH)		.010			
Electrical Expense			2033		
Gas Usage (therms)	(000)	4464			
Rate ($/therm)		.22			
Gas expense			982		
Aircraft fuel (gal)	(000)	3703			
Rate ($/gal)		.37			
Aircraft fuel expense			1370		
				4385	
Capital					
Depreciation/Rent/Res			32,483		
Inventory book value		212,194			
Cost of capital		.11			
Inventory cost			23,341	-	
				55,824	
TOTAL INPUTS				428,912	

APPENDIX A-1

1977

OUTPUTS

Labor Improvement Factor 1.00

		Actuals (Q_2P_2)		Deflated (Q_2P_1)
EMU, actual		4398.72		NA
EMU, with LIF		4398.72		
Output labor rate	(\$/hr.)	24.18		
Labor output revenue	(\$000)		202,086	
Labor output revenue w/ LIF			202,086	
Materials				
Maintenance Materials	(\$000)	131,120		
(less Purchased Maint)		(145,137 - 14,017)		
Material Mark-up rate		1.324		
Material Revenue	(\$000)		173,603	
Purchased Maint	(\$000)	14,017		
Purchased Maint Mark-up		1.15		
Purchased Maint Revenue			16,120	
TOTAL OUTPUT WITHOUT LIF	(\$000)		391,809	
TOTAL OUTPUT WITH LIF	(\$000)		391,809	

APPENDIX A-2

1978

INPUTS ($000) except as noted

		Actuals	$(Q_2\ P_2)$		Deflated	$(Q_2\ P_1)$	
Actual hours worked	(000)	14,595			14,595		
Hourly wage	($/hr.)	14.76			13.53		
Personnel expense				215,393			197,470
Personnel related				661			661
Maintenance Materials		136,716			133,251 (w/inventory value 1.026		
Cost of Sales		3381			3,381		
Miscellaneous		2717			2,717		
Ground equip & radio		195			195		
Fac/Comm/Tax/Other		7383		150,392	7,383		146,927
Energy							
Electrical usage (KWH)	(000)	134,870			134,870		
Rate ($/KWH)		.023			.02		
Electrical Expense			3102			2697	
Gas Usage (THERMS)	(000)	3954			3954		
Rate ($/THERM)		.28			.22		
Gas expense			1107			870	
Aircraft fuel (GAL)	(000)	3372			3372		
Rate ($/GAL)		39			.37		
Aircraft fuel expense			1315	5524		1248	4815
Capital							
Depreciation/Rent/Res			32421			32421	
Inventory book value		200,962			195,869 (w/inventory value 1.026		
Cost of capital		.11			.11		
Inventory cost			22106	- 54,527		21546	53,967
TOTAL INPUTS				426,497			403,840

APPENDIX A-2

1978

OUTPUTS

Labor Improvement Factor = 1.026

		Actuals	(Q_2P_2)	Deflated	(Q_2P_1)
EMU, actual		4130.07		4130.07	
EMU, with LIF		4237.45		4237.45	
Output labor rate	($/hr.)	25.58		24.18	
Labor output revenue	($000)		200,730		189,744
Labor output revenue w/LIF	($000)		205,949		194,677
Materials					
Maintenance Materials	($000)	123,627		120,494 (w/inventory value 1.026)	
(less Purchased Maint)		(136,716 - 13,089)			
Material Mark-up rate		1.297		1.324	
Material Revenue	($000)		160,344		159,534
Purchased Maint	($000)	13,089		12,757	
Purchased Maint Mark-up		1.15		1.15	
Purchased Maint Revenue	($000)		15,052		14,671
TOTAL OUTPUT WITHOUT LIF	($000)		376,126		363,949
TOTAL OUTPUT WITH LIF	($000)		381,345		368,882

APPENDIX A-3

1979

INPUTS ($000) except as noted

		Actuals	$(Q_2\ P_2)$		Deflated	$Q_2\ P_1)$	
Actual hours worked	(000)	14515			14515		
Hourly wage	($/hr.)	16.91			13.53		
Personnel expense				245,419			196,388
Personnel related				774			774
Maintenance Materials		151,574			142,994	(w/inventory value 1.06)	
Cost of Sales		3023			3023		
Miscellaneous		1187			1187		
Ground equip & radio		179			179		
Fac/Comm/Tax/Other		7409		163,372	7409		154,792
Energy							
Electrical usage (KWH)	(000)	96,500			96,500		
Rate ($/KWH)		.03			.02		
Electrical Expense			2895			1930	
Gas usage (THERMS)	(000)	4367			4367		
Rate ($/THERMS)		.33			.22		
Gas expense			1441			961	
Aircraft fuel (GAL)	(000)	2807			2807		
Rate ($/Gal)		.56			.37		
Aircraft fuel expense			1572	5908		1039	3930
Capital							
Depreciation/Rent/Res			33,447			33,447	
Inventory book value		188,723			178,041	(w/inventory value 1.06)	
Cost of capital		.12			.11		
Inventory cost			22,647	56,094		19,585	53,032
TOTA' INPUTS				471,567			408,916

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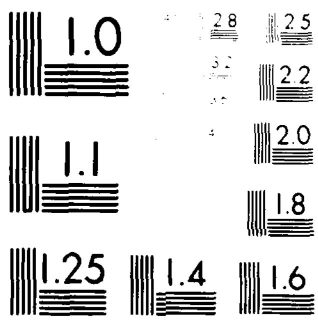

MICROCOPY RESOLUTION TEST CHART

APPENDIX A-3

1979

OUTPUTS

Labor Improvement Factor = 1.041

		Actuals $(Q_2\ P_2)$		Deflated $(Q_2\ P_1)$		
EMU, actual		3975.99		3975.99		
EMU, with LIF		4139.0		4139.0		
Output labor rate	(\$/hr.)	28.14		24.18		
Labor output revenue	(\$000)		212,580		182665	
Labor output revenue w/LIF	(\$000)		221,296		190154	
Materials						
Maintenance Materials	(\$000)	138652		130,804		(w/inventory value 1.06)
(less Purchased Maint)		(151574-12922)				
Material Mark-up rate		1.339		1.324		
Material Revenue	(\$000)		185,655		173,184	
Purchased Maint	(\$000)	12,922		12,191		
Purchased Maint mark-up		1.15		1.15		
Purchased Maint Revenue	(\$000)		14,860		14,020	
TOTAL OUTPUT WITHOUT LIF	(\$000)		413,095		369,869	
TOTAL OUTPUT WITH LIF	(\$000)		421,811		377,358	

APPENDIX A-4

1980

INPUTS

		Actuals	$(Q_2\ P_2)$		Deflated	$(Q_2\ P_1)$	
Actual hours worked	(000)	13,424			13,424		
Hourly wage	($/hr.)	18.72			13.53		
Personnel expense				251,289			181,627
Personnel related				1,012			1,012
Maintenance Materials		156,425			141,178	(w/inventory value 1.108)	
Cost of Sales		2,603			2,603		
Miscellaneous		696			693		
Ground equip & radio		228			228		
Fac/Comm/Tax/Other		7,869			7,869		
				167,821			152,574
Energy							
Electrical usage (KWH)	(000)	84,172			84,172		
Rate ($/KWH)		.0386			.02		
Electrical Expense			3,249			1,683	
Gas usage (THERMS)	(000)	4,325			4,325		
Rate ($/THERM)		.13			.22		
Gas expense			1,860			952	
Aircraft fuel (GAL)		2,199			2,199		
Rate ($/GAL)		.875			.37		
Aircraft fuel expense			1,924			814	
				7,033			3,449
Capital							
Depreciation/Rent/Res			32,249			32,249	
Inventory book value		190,401			171,842	(w/inventory value 1.108)	
Cost of capital		.13			.11		
Inventory cost			24,752			18,903	
				57,001			51,152
TOTAL INPUTS				484,156			389,814

APPENDIX A-4

1980

OUTPUTS

Labor Improvement Factor = 1.115

		Actuals	(Q_2 P_2)	Deflated	(Q_2 P_1)	
EMU, actual		3648.89		3648.89		
EMU, with LIF		4068.51		4068.51		
Output labor rate	($/hr.)	31.69		24.18		
Labor output revenue	($000)		219,703		167,640	
Labor output revenue w/ LIF	($000)		244,964		186,911	
Materials						
Maintenance Materials	($000)	137,864		124,426		(w/inventory value 1.108
(less Purchased Maint)		(156,425 - 18,561)				
Material Mark-up rate		1.337		1.324		
Material Revenue	($000)		184,324		164,740	
Purchased Maint	($000)	18,561		16,752		
Purchased Maint mark-up		1.15		1.15		
Purchased Maint Revenue	($000)		21,345		19,265	
TOTAL OUTPUT WITHOUT LIF	($000)		425,372		351,645	
TOTAL OUTPUT WITH LIF	($000)		450,63[illegible]		370,916	

APPENDIX B

PRODUCTIVITY CALCULATION SUMMARY

1978

$$P = \frac{\dfrac{Q_2^U P_1^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_1^I}{Q_1^I P_1^I}} = \frac{\dfrac{368,882}{391,809}}{\dfrac{408,840}{428,912}} = \frac{.9415}{.9415} = .999$$

1979

$$P = \frac{\dfrac{Q_2^U P_1^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_1^I}{Q_1^I P_1^I}} = \frac{\dfrac{377,358}{391,809}}{\dfrac{408,916}{428,912}} = \frac{.9631}{.9534} = 1.010$$

1980

$$P = \frac{\dfrac{Q_2^U P_1^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_1^I}{Q_1^I P_1^I}} = \frac{\dfrac{370,916}{391,809}}{\dfrac{389,814}{428,912}} = \frac{.9467}{.9088} = 1.042$$

APPENDIX C

PRICING RECOVERY CALCULATION SUMMARY

1978

$$R = \frac{\dfrac{Q_2^U P_2^U}{Q_2^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_2^I P_1^I}} = \frac{\dfrac{376,126}{368,882}}{\dfrac{426,497}{403,840}} = \frac{1.0196}{1.0561} = .965$$

1979

$$R = \frac{\dfrac{Q_2^U P_2^U}{Q_2^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_2^I P_1^I}} = \frac{\dfrac{413,095}{377,358}}{\dfrac{471,567}{408,916}} = \frac{1.095}{1.153} = .949$$

1980

$$R = \frac{\dfrac{Q_2^U P_2^U}{Q_2^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_2^I P_1^I}} = \frac{\dfrac{425,372}{370,916}}{\dfrac{484,156}{389,814}} = \frac{1.147}{1.242} = .923$$

APPENDIX D

COST EFFECTIVENESS CALCULATION SUMMARY

1978

$$E = \frac{\dfrac{Q_2^U P_2^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_1^I P_1^I}} = \frac{\dfrac{376,126}{391,809}}{\dfrac{426,497}{428,912}} = \frac{.960}{.9944} = .965$$

1979

$$E = \frac{\dfrac{Q_2^U P_2^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_1^I P_1^I}} = \frac{\dfrac{413,095}{391,809}}{\dfrac{471,567}{428,912}} = \frac{1.054}{1.099} = .959$$

1980

$$E = \frac{\dfrac{Q_2^U P_2^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_1^I P_1^I}} = \frac{\dfrac{425,372}{391,809}}{\dfrac{484,156}{428,912}} = \frac{1.086}{1.129} = .962$$

APPENDIX E

VARIANCE CALCULATION RESULTS

A. COST EFFECTIVENESS VARIANCE

$C_1 = PQ^I (VI^u - VI^I)$

	1978	1979	1980
C_1 (LABOR)	-7409	-11073.8	-10840.3
C_1 (MATERIAL)	-4703	-6839.3	- 6748
C_1 (CAPITAL)	-1876	-2531.1	- 2459
C_1 (ENERGY)	- 190	- 266.6	- 303.4

B. PRODUCTIVITY VARIANCE

$C_2 = PQ^I (QI^u - QI^I)$

	1978	1979	1980
C_2 (LABOR)	- 13	2390	9506.7
C_2 (MATERIAL)	- 8.3	1476	5917.8
C_2 (CAPITAL)	- 3.3	546.2	2156.4
C_2 (ENERGY)	- 0.3	57.5	266.1

C. PRICING RECOVERY VARIANCE

$C_3 = C_1 - C_2$

	1978	1979	1980
C_3 (LABOR)	-7396	-13463.3	-20346.7
C_3 (MATERIAL)	-4694.7	-8315.3	-12665.8
C_3 (CAPITAL)	-1872.7	-3077.3	- 4615.4
C_3 (ENERGY)	- 189.7	- 324.1	- 569.5

NOTE: DATA EXPRESSED IN THOUSANDS OF DOLLARS

VARIANCE CALCULATION SUMMARIES

A. COST EFFECTIVENESS VARIANCE $C_1 = PQ^I (VI^u - VI^I)$

	1978	1979	1980
C_1 (LABOR)	215,393(.96-.994)	245,419(1.054-1.099)	251,289(1.086-1.129)
C_1 (MATERIAL)	136,716(.96-.994)	151,574(1.054-1.099)	156,425(1.086-1.129)
C_1 (CAPITAL)	54,527(.96-.994)	56,094(1.054-1.099)	57,001(1.086-1.129)
C_1 (ENERGY)	5,524(.96-.994)	5,908(1.054-1.099)	7,033(1.086-1.129)

B. PRODUCTIVITY VARIANCE $C_2 = PQ^I (QI^u - QI^I)$

	1978	1979	1980
C_2 (LABOR)	215,393(.942-.9415)	245,419(.963-.953)	251,289(.947-.909)
C_2 (MATERIAL)	136,716(.942-.9415)	151,574(.963-.953)	156,425(.947-.909)
C_2 (CAPITAL)	54,527(.942-.9415)	56,094(.963-.953)	57,001(.947-.909)
C_2 (ENERGY)	5,524(.942-.9415)	5,908(.963-.953)	7,033(.947-.909)

C. PRICING RECOVERY VARIANCE $C_3 = C_1 - C_2$

	1978	1979	1980
C_3 (LABOR)	-7409 - (-13)	-11,073.8-2390	-10,840.3-9506.7
C_3 (MATERIAL)	-4703 - (-8.3)	- 6,839.3-1476	- 6,748 -5917.8
C_3 (CAPITAL)	-1876 - (3.3)	- 2,531.1- 546.2	- 2,459 -2156.4
C_3 (ENERGY)	- 190 - (-0.3)	- 266.6- 57.5	- 303.4- 266.1

NOTE: DATA EXPRESSED IN THOUSANDS OF DOLLARS

APPENDIX F

INDEX CALCULATION SUMMARIES

WITHOUT LABOR IMPROVEMENT FACTOR

1978

$$\text{PRODUCTIVITY INDEX} \quad P = \frac{\dfrac{Q_2^U P_1^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_1^I}{Q_1^I P_1^I}} = \frac{\dfrac{363,949}{391,809}}{\dfrac{403,840}{428,912}} = .987$$

$$\text{PRICING RECOVERY INDEX} \quad R = \frac{\dfrac{Q_2^U P_2^U}{Q_2^U P_1^I}}{\dfrac{Q_2^I P_2^I}{Q_2^I P_1^I}} = \frac{\dfrac{376,126}{363,949}}{\dfrac{426,497}{403,840}} = .9785$$

$$\text{COST EFFECTIVENESS INDEX} \quad E = \frac{\dfrac{Q_2^U P_2^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_1^I P_1^I}} = \frac{\dfrac{376,126}{391,809}}{\dfrac{426,497}{428,912}} = .965$$

INDEX CALCULATION SUMMARIES

WITHOUT LABOR IMPROVEMENT FACTOR

1979

PRODUCTIVITY INDEX

$$P = \frac{\dfrac{Q_2^U P_1^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_1^I}{Q_1^I P_1^I}} = \frac{\dfrac{369,869}{391,809}}{\dfrac{408,916}{428,912}} = .99$$

PRICING RECOVERY INDEX

$$R = \frac{\dfrac{Q_2^U P_1^U}{Q_2^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_2^I P_1^I}} = \frac{\dfrac{413,095}{369,869}}{\dfrac{471,567}{408,916}} = .9685$$

COST EFFECTIVENESS INDEX

$$E = \frac{\dfrac{Q_2^U P_2^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_1^I P_1^I}} = \frac{\dfrac{413,095}{391,809}}{\dfrac{471,567}{428,912}} = .959$$

INDEX CALCULATION SUMMARIES
WITHOUT LABOR IMPROVEMENT FACTOR

1980

PRODUCTIVITY INDEX
$$P = \frac{\dfrac{Q_2^U P_1^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_1^I}{Q_1^I P_1^I}} = \frac{\dfrac{351,645}{391,809}}{\dfrac{389,814}{428,912}} = .9875$$

PRICING RECOVERY INDEX
$$R = \frac{\dfrac{Q_2^U P_2^U}{Q_2^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_2^I P_1^I}} = \frac{\dfrac{425,372}{351,645}}{\dfrac{484,156}{389,814}} = .974$$

COST EFFECTIVENESS INDEX
$$E = \frac{\dfrac{Q_2^U P_2^U}{Q_1^U P_1^U}}{\dfrac{Q_2^I P_2^I}{Q_1^I P_1^I}} = \frac{\dfrac{425,372}{391,809}}{\dfrac{484,156}{428,912}} = .962$$

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